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Dissertation

Urban Sketcher: Mixing Urban Realities using Mixed Reality Technology

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Städteplanung und Gestaltung muss umfangreiche Aspekte, die Gesellschaft und die bebaute Umgebung betreffen, berücksichtigen und erforschen. Deshalb sind Stadtbauprojekte extrem komplex. Sie spielen eine immer wichtigere Rolle in der Gesellschaftspolitik und betreffen Investoren, technische Spezialisten und nicht zuletzt Bürger. Es ist wünschenswert diese Akteure schon frühzeitig in den Planungsprozess mit einzubeziehen, damit ihre verschiedenen Standpunkte erfolgreich geäußert und verstanden werden können. In dem Prozess werden Standpunkte gegenübergestellt und weiterentwickelt, damit schließlich eine gemeinsame Vision durch das Projekt erzielt und repräsentiert wird. Dabei spielt der Informationsaustausch eine Schlüsselrolle.

Motivation dieser Arbeit ist es, die Kommunikations- und Entscheidungsprozesse mit Mixed Reality (MR) zu unterstützen. MR ist eine Symbiose von realer Welt und virtuellem Informationsraum, welche beide unter Berücksichtigung der menschlichen Wahrnehmung durch die MR-Technologie synchronisiert werden. MR kann im fortlaufenden Prozess der menschlichen Kommunikation, Entwicklung und Teamarbeit vermitteln. Engagement aller Akteure, um auszudrücken wie sie die Realität verstehen, und um zu erfahren, wie andere die Realität verstehen, gehört zum Prozess der als Mixing Realities bezeichnet werden kann.

Gemeinsame Anstrengungen im IPCity[1] Projekt führten zu mehreren partizipativen Workshops auf Bauplätzen in realen urbanen Planungssituationen, um Mixing Urban Realities unter Verwendung von MR-Technologie zu ermöglichen. Das Design mit dem Anwender im Mittelpunkt trug zum kontinuierlichen Zyklus Implementierung-Evaluierung-Verbesserung von Urban Sketcher und seinen MR-Werkzeugen bei, um in Verbindung mit einem MR-Zelt einen interaktiven Arbeitsraum in der urbanen Umgebung zu formen. In einer Anwendungsstudie wurden zweihändige Schnittstellen zur Darstellungs-Navigation und Szenen-Manipulation in Verbindung mit einem Miniaturmodell untersucht. Signifikante Unterschiede für Task-Ausführungszeiten, Unterstützung von Anwendern mit unterschiedlichen Rollen und Fähigkeiten sowie Anwenderpräferenzen, die das Design von Navigation und Interaktion betreffen, sind Resultate.

Für die gemeinsame Nutzung von MR mit den Ziel Verhandlungen zu schlichten und Zusammenarbeit zu fördern, wurden Schnittstellen in Grenzbereichen optimiert und natürliche Zusammenhänge in Betracht gezogen. Skizzieren, Erstellen und Platzieren von Inhalten mit den entwickelten MR-Werkzeugen kann individuelle Beiträge ermutigen. Kommunikation mit direktem Blickkontakt und entstandenen MR-Schnittstellen fördert und harmonisiert urbane Kommunikations- und Entscheidungsprozesse.

Zukünftige Entwicklungen können Beiträge durch ubiquitäre Kooperationen vereinigen, die "Mixing urban realities"-Prozesse durch soziales und natürliches Design, sowie integrieren von fortschrittlicher Computergrafik und Bildverarbeitung fördern. Partizipation und Engagement zusätzlicher Akteure tragen zur Entwicklung von kollektivem Bewusstsein in Bezug auf Risiken und Chancen bei, während Verantwortung geteilt und Legitimität von Projekten verbessert wird, um reale Probleme nachhaltig anzupacken.

1 IPCity Integriertes Mixed Reality Projekt – Teil des 6. Rahmen Programms der Europäischen Kommission (FP-2004-IST-4-27571)

Abstract

Urban planning and design needs to explore a wide range of aspects concerning the built and social environment. Hence, city-development projects are vastly complex; they affect investors, technical specialists and citizens, and they play an increasing role in community politics. It is desirable to involve the stakeholders from an early stage in the planning process, to enable their different viewpoints to be successfully expressed and comprehended. The objective of this process is to confront and refine these viewpoints and to ultimately achieve a common vision represented by the urban project. The exchange of information is the key in this process, mediating technology aids the individuals' engagement and their understanding of the urban planning issues at stake.

The motivation behind this thesis is to enhance such communication processes and decision making with Mixed Reality (MR). MR is a symbiosis of the real world and a virtual information space which are synchronized by MR technology with respect to human perception. MR mediates the ongoing process of human communication, development and collaboration where individuals engage to express their understanding of reality and engage to experience the understanding of others, which can be described as mixing realities.

This thesis concentrates on the development of MR technology infrastructure and on the integration as well as the design of MR tools for enhancing urban communication processes. For mixing urban realities using MR technology joint efforts in the IPCity[2] project led to several participatory workshops on site, in real urban planning situations. User-centered design contributed to the continuous cycle of implementation, evaluation and refinement of Urban Sketcher and its MR tools to form an interactive workspace, using an MR Tent in the urban environment. In a user study, the author investigated bimanual handheld interfaces for view navigation and scene manipulation using a tabletop model. Results are: significant differences in task completion times, support for differing roles and expertise as well as user preferences and practical issues concerning both interface and view navigation design.

Interfaces were designed to optimize seams and consider natural mappings for using a shared information space to allow conciliation and negotiation and encourage collaboration. Individual contributions can be encouraged by MR tools for sketching, creating and placing MR content. Unobstructed face-to-face communication in combination with joint navigation and interaction utilizing the shared information space, Mixed Reality, is helpful for documenting, enhancing and harmonizing urban communication and decision processes.

Future work has the potential to unite contributions, aiding the mixing of urban realities by ubiquitous cooperation, which drives social and natural design as well as the integration of advanced computer graphic and vision tools. Wider stakeholder participation and engagement permits the development of collective consciousness about issues at stake while sharing responsibility and improving legitimacy of projects to sustainably tackle real-world problems.

2 IPCity Integrated Mixed Reality Project – Part of the European Commission 6th Framework Program (FP-2004-IST-4-27571)

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I would like to thank everybody without whom this dissertation would not have been possible. First, I would like to thank my supervisor Prof. Dieter Schmalstieg for the opportunity of joining his research group and working in the area of Mixed Reality. During my time at the Graz University of Technology, I learned a lot about research, leadership and team work. Second I would like to thank my supervisor Prof. Holger Regenbrecht for fruitful discussions. Furthermore, I want to thank the research team around the Institute for Computer Graphics and Vision for lively and critical conversations as well as for a stimulating working environment and support. I would further like to thank the team at HITLab New Zealand and especially Raphael Grasset who inspired me during my research visit. Acknowledgments also go to coworkers from the European IPCity project without whom I would not have been able to progress in the way I did. In addition I want to thank Dr. Wlasak for psychological insights and mental support. I am grateful to my family who always believed in my scientific career and who supported me in my studies and personal development.

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Chapter 1

Introduction

1.1 Evolving Live Communication Technology

Live events and broadcasts are the highlights in today's society and address masses of recipients, streaming multi-sensory information which is mostly auditory and visual, into the living rooms and stadiums, spreading new stimuli from one directed scene to many individuals. Technically speaking this is a multicast, one-way communication in real-time.

In 1826 the era of the technically reproducible artwork was introduced with the first photograph. The following evolution of technology brought at first jerking, silent, monochromatic images to theaters which started to slowly spread around our globe. In the course of time developments brought moving images in color with sound and changes in distribution technology. It evolved from celluloid, first used in cinemas to electronic representations, starting with radio transmissions. This technical advancement introduced the real-time capability. The new-born broadcasting technology allowed one to reach masses of people owning a receiver. At first auditive live content distribution such as daily news broadcasts became common. As soon as technology was available, additionally the visual channel was sent to the recipients. Nowadays television is regarded as a basic right in modern societies and coexists with many other real-time capable media transmission systems like various internet devices and services.

Today, the flow of information is still directed by the broadcasters who are slowly starting to introduce controlled back channels into their programs, so information can be transmitted from the individual to the directed broadcasting scene, giving some content control to the user. This process is mainly fostered by the world wide web, also known by the public as the internet or cyberspace, which has no limitations in terms of information channel number, temporal restrictions, direction and control. Nowadays its acceptance is higher than the widespread, established and somewhat restricted media broadcasting scene[3].

New communication features always had an impact on how the information distribution takes place and how it is available for the perception of the individual. Just as Walter Benjamin mentioned in his essay "*Das Kunstwerk im Zeitalter seiner technischen Reproduzierbarkeit*" *(The Work of Art in the Age of Mechanical Reproduction) [19]*, a precise analysis of current production and reception conditions, the technological advancement is responsible for a changing character in art. The masses are a matrix from which all present accustomed behavior towards art work emerges new born [19]. The pioneering theoretical media analysis had special influence on art theory and film critique in the seventies and is one of the grounding documents for culture and media theory of modernity [18].

Due to the technical evolution since Benjamin`s publication, the individual is no longer just a recipient but is now in the position to interact live in real-time, giving her control and the ability to influence the transmitted information. Some of these new emergent trends are examined in more detail now, relevant for the growing information space around the individual. A recent development concerning communication technology is mobility, which allows immediate asynchronous and synchronous exchange of information in real-time at almost any place. The location independency introduced by mobile technology called for a new feature, the indication of the current location.

3 http://www-03.ibm.com/press/us/en/pressrelease/22206.wss (13.09.2010)

Location

Location means position and orientation within a coordinate system.

Localization by GPS [41] and soon Galileo[4] provides the mobile communication device with its current global position. The current orientation can be provided by integrated sensors like a compass. With the information on the physical location in space, a map contained in the device can be georeferenced and as a result support navigation and enrich the individual information space.

Georeference

Georeferencing means to determine the spatial position of something in physical space and aligning its coordinate system to the Earth's surface, *e.g.* finding one's position on a map, and orient it in the correct direction (north) or using an overriding coordinate system so that different sources of geographic data can be referenced to the Earth's surface in the same way.

The trend for the flow of information is towards bidirectional live exchange between mobile individuals. Context information gathered by various sensors around the mobile device is available and can be utilized for sharing the current individual situation [110]. In addition, collected and created media, *e.g.,* images and video clips, are used to distribute and share personnal data among friends, colleagues or special interest groups [114]. This enriches the communication bandwidth and can lead to a higher awareness of each other (more information is available which one can be aware of). As physical borders are overcome with the help of mobile technology, a basis for collaboration between people is created *for example.* with mobile games such as “*Human Pacman*” [35]. Increasing engagement in a growing shared information space interlinks people by providing various channels for immediate interaction. The rapid developing technology therefore plays an increasingly important role for social interaction [75] and services [113].

Communication Bandwidth

Communication bandwidth is the amount of information transferred within one time unit (*e.g.,* second) between two entities in both directions. Both entities can either be human or computer.

Looking into the near future we will have mobile technology on the market supporting our bidirectional communication needs at a higher level, meaning not only the already available georeferencing,

4 http://www.esa.int/esaNA/galileo.html (13.09.2010)

audio and texting services, in real-time, but also enhanced high-bandwidth data and high-definition video services. In addition to that, available computation power for mobile applications will keep rising at high rates [176]. A limiting factor will probably be the mobile power source, calling for ground-breaking inventions [127].

However, future mobile devices will further improve communication bandwidth for the individual, enrich the information space and provide more communication cues. High quality remote collaboration tools will then be available on mobile devices.

Mediate

> To act between parties to effect an agreement, compromise, reconciliation, *e.g.,* by information transmission or information interpretation. Computer-mediated communication (CMC) is any communicative transaction between two or more entities using any kind of digital media format.

The field of computer supported cooperative work (CSCW) [74] is focused on the development of collaboration support by the computer. In 2001, "*Many organizations are using a variety of first- and second-generation collaborative virtual design environments routinely as a foundation for collaborative virtual design and product development*" [132]. Tools supporting the Human-Computer interface became more common preparing the way for Human-Human interfaces mediated by computers. Remote and face-to-face communication are addressed. Collaborative workspaces created by the communication tools often introduce *seams* and discontinuities, which were defined by Ishii as spatial, temporal or functional constraints [71].

Seams

> Seams interrupt continuity of information flow. They can occur in workflows, functional spaces and interfaces. The discontinuities of spatial or temporal cues are often related to increased cognitive load.

Seams in collaborative interfaces change the nature of collaborators' communication behavior. For instance, remote collaborations mediated by video streams are "*... introducing certain asymmetries into the social interaction between users*" [59].

Evolving live communication technologies like mobile devices override physical space and contribute to densely growing communication between people at any time and place by integrating CSCW tools [125], but in-person face-to-face communication is vastly rich and can not easily be substituted by remote communication technology.

Similar to the new communication technologies, face-to-face communication is live, and in the same physical space and commonly preferred in complex situations or if something is at stake. For decision making it was found, that "*... there was a very striking difference in the ability of the group to reach total consensus.*" [62] when communicating face-to-face instead of using computer mediated text messaging. Results of another study indicated "*... that while the internet was integrated into college students' social lifes, face-to-face communication remained the dominant mode of interaction*" [14]. Findings in the field of computer-supported collaborative learning state that: "*The key to the efficacy of collaborative learning is social interaction, and lack of it is a factor causing the negative effectiveness of collaborative learning*" [86].

In summary, live face-to-face communication is preferred and often more effective for decision making, social interaction and learning. To make communication in these situations even more effective, technology can be used to enhance perception. It is already common to use visual presentation tools in education, collaborative work or meeting situations, to enrich the live communication with technology.

The human visual sense collects impressions connecting the individual to reality. This sense engages up to 90% of human perception. It is vastly complex and comprises numerous components and interactions between them, which have not yet all been fully studied and understood by several involved fields of science [148]. That makes it especially interesting for collaborative communication situations with eye contact involving mediating technology such as: "*Perceptual user interfaces: multimodal interfaces that process what comes naturally*" [123]. Traditionally computers and their interfaces are artificial, thus not natural. Humans learn artificial behaviors in contradiction to their natural communication habits when using computers for exchanging information. "*Natural mapping, by which I mean taking advantage of physical analogies and cultural standards, leads to immediate understanding*" [119]. Natural designed interfaces utilize natural mappings, adapt to the users natural communication behavior and reduce learning, thus enabling the user to interact with information and the space containing it more intuitive.

Digital information can represent almost anything created by human imagination [1], which is important for communicating ideas and future visions involving development, education and cooperative work.

A mixture of the live interaction as part of the real world, with the artificial digital information mediated by computer interfaces, form a new kind of reality, *Mixed Reality,* which is defined in detail in the next section.

1.2 Mixed Reality Used for Mixing Realities

The development in the sense of Mixed Reality technology started with the era of technological reproducible art work when the first photographs where shot [19]. Only a visual channel was available and the transfer time was rather slow (developing a picture took several hours) compared to the real-time technologies used nowadays. This form of creating a virtual copy of reality was restricted to information flow in one direction, similar to the television and cinema today, which record and show image sequences at such a speed that motion elements in the imagery are perceived as continuous by the human recipient.

Cinematography can be understood as the professional art of fusing directed virtual and real scene elements into new images aimed at influencing human perception, allowing the individual to enter an artificially generated world. Imagination is driven by the perception. The phantasy- and dream worlds inductively generated by the recipient of cinematographic work are different from the artificially generated worlds in Virtual Reality (VR). The challenging goal for some developers is to achieve the perfect illusion of synthetic worlds of VR, making them indistinguishable form the real world. Immersion can be understood as the measure or impression of how well those simulated worlds resemble reality. Several attempts exist to define the term either qualitatively [144] [177] or by subjective ratings [60]. Pausch *et al.* try to quantify immersion in VR [126]. However, immersive qualities increase as media technology develops. Burdea and Coiffet [31] abstract immersion, interaction and imagination as “I^3”, the goals of virtual reality. They define VR as a progressive user interface allowing simulation and interaction in real time by using multiple sensory channels. The sensual modalities are visual, auditory, tactile, olfactory and gustatory. The holodeck[5] of Star Trek is a classical fictional depiction of such a synthetically generated world. The perfect illusion of the holodeck may be considered as a pure fictional construction, but considering projects like the AlloSphere[6] [66] proves that real-world technology is being developed in this direction in order to further explore technology itself as well as its effects on various fields of art and science [4].

Increasing visual, auditory, tactile, olfactory, gustatory and temporal factors for representing the digital information, which defines those artificial spaces, shrinks the gap between real and virtual. With the introduction of interaction, the exchange of information and the support of kinaesthetic factors, the individual perceptual motor loop [143] is intrinsically linked to the artificial spaces. As a result, the exchange of information cues between man and machine is increased by simultaneous multi-sensory communication. An ideal interface design must "*... allow users to interact naturally*" [91]. The available communication bandwidth can be used in CSCW for sharing ideas and developing future visions by supporting interhuman communication mediated by artificial information spaces in the context of science, art, games, education, social interaction, urban processes, and decision making.

Figure 1: Mixed Reality Continuum

Mixed Reality (MR) was defined as reality continuum combining real and synthetic worlds [108]. Within this continuum spanning real and virtual (Figure 1), Augmented Reality (AR) [109] describes a mainly real environment augmented by virtual objects, while Augmented Virtuality (AV) [134] is a virtual environment augmented by real objects. A good reference roughly summarizing the research on AR is this bibliography [2], recent trends in AR are outlined in the

5 http://www.startrek.com/database_article/holodeck (14.09.2010)

6 http://www.allosphere.ucsb.edu/about.php (14.09.2010)

publication of Zhou *et al.* [179]. Mixed Reality in related work mainly addresses the reality continuum. To consistently build on the stated definitions and goals from VR including I^3, MR should inherit them.

In the European IPCity Research Project[7] a wide range of expertise is encompassed, and therefore necessarily a broad approach towards using and studying MR was taken. Based on the author's experience made during the project, it is suggested that MR should be interpreted as a very broad concept. Summarizing influential factors and related work a new definition is stated:

Mixed Reality

MR technology fuses information between virtual spaces and the real world for the perception and interaction of humans. Mixed Reality is a symbiosis of spaces which are synchronized with respect to human perception. One space corresponds to the usual environment of humans, the other is virtual and exists digitally. It contains information which is mostly exchanged in the form of objects representing and combining (haptic, olfactory, gustatory) visual and auditory channels. As a result, the individual's perception is directly influenced by Mixed Reality interfaces which condition the communication with Mixed Reality, the workspace.

The exchange of information between the advanced user interface of MR technology and the individual perception of the user is effected by utilizing multi-sensory channels. Human perception is the result of all processed information which was aggregated by all stimulated senses. Overall stimuli are felt and perceived as what they are [90]. As result of perception and cognition, actions are directed from the individual expressing her insight mostly using speech and kinaesthetic output performance, closing the communication loop [143] between the user and the digital information space. Displays are used as MR interfaces to the digital information space. Experience with the use of multiple displays leads to the following definition:

Mixed Reality Boundaries

Milgram & Kishino [108] describe MR as the combination of real environment and virtual environment "*presented together within a single display.*" Benford et al. [17] argue that a complex environment will often be composed of multiple displays and adjacent spaces. These multiple spaces meet at "*Mixed Reality boundaries*".

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7 http://www.ipcity.eu/ (14.09.2010)

Depending on the design, MR boundaries introduce seams, which influence immersion, and these can be interpreted in various ways. For clarity immersion is now defined for further use:

Immersion

> Immersion is an intensity impression of an individual human engaged in experiencing as well as expressing multi-sensory information.

Immersion is mainly influenced by the achieved bandwidth of bidirectional communication between the human and the environment. User interface design is responsible for the available information exchange bandwidth between the user and MR. It is up to the user to engage herself with the MR environment and therefore to select and use available bandwidth for supporting her task and communicating her intention. The exchange of information among humans involves more than one person and requires cooperation.

To the author's knowledge, the term *mixing realities* (mr) was first used by Benford *et al.* [17], and later to describe collaborative AR [22]. “Collaborative Mixed Reality” [21] is the publication of Billinghurst looking into 3D CSCW. For clarity, a new definition of mixing realities will be formulated, combining the meanings used in the mentioned related work, now consistently building upon the new defined term Mixed Reality, including collaboration:

Mixing Realities

> Mixing realities is an ongoing process of human communication, development and collaboration, where individuals engage to express their personal understanding of reality and engage to experience the understanding of others, mediated by the unified workspace provided by Mixed Reality.

The process of mixing realities has only become possible since the enabling technology has been made available, which means that multiple MR users can be simultaneously engaged in a collaborative mediated interaction process. Such working environments, involving several individuals, are designed to support workflows and are aimed at improving communication. Complex tasks are part of the work with urban processes and require expertise from disjunctive professional fields as well as insights from casual people for building communication bridges [124]. Individual experience, expression and reflection contributes to the mixing realities communication process, engaging consciousness.

There is a need for tools to aid the individual engaged in mixing realities to express her intention. Complex tasks can be tackled with the support of various roles in one workspace. MR interfaces are instrumental for human integration and cooperative work. A natural and efficient design is the goal for the input and output interfaces, so continuous interactions at low cognitive loads can be achieved. It was found that interaction significantly lowers cognitive load of students involved in solving rule-based complex tasks using multimedia [178]. These findings can not be easily generalized, but suggest further investigation involving effects of mediating interfaces on cognitive load when solving complex tasks, which can be relevant for effective communication in mixing realities processes and for improving the design of MR interfaces aimed at optimal information exchange bandwidth in real time.

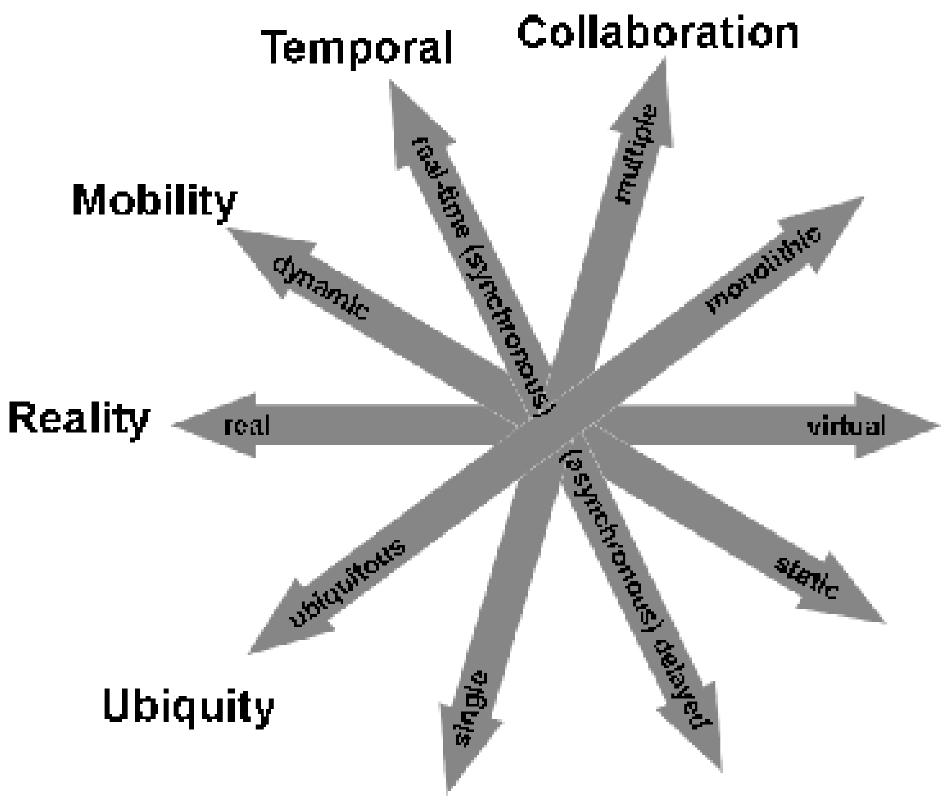

Figure 2: Continuum Spanning MR Technology Aspects

From a technical point of view, MR was initially described as a continuum by Milgram [108]. Independently, Weiser examined ubiquity [174], which is obviously important for interface devices. These considerations were always kept distinct. The publication of Newman *et al.* [116] suggests to organize ubiquitous MR applications in a two-dimensional Milgram-Weiser continuum, taking the quantity and density of spatial distribution in to account. This approach is better able to represent configurations where multiple input and output devices are interconnected to contribute to MR systems blurring the border to ubiquitous computing. A similar 3-dimensional taxonomy, covering immersion, collaboration and mobility, was proposed earlier by Broll [29]. So far suggested taxonomies for describing the design space of MR technology aspects are not sufficiently expressive in reflecting all aspects encountered during the research done in the IPCity project, consequently in Figure 2 the author suggests a five-dimensional continuum enclosing reality, ubiquity, mobility, temporal aspects and collaboration.

Continuum for MR Technology Aspects

Mixed Reality Technology is influenced and described by numerous aspects. According to the definition of **Mixed Reality** in this work, it is a symbiosis of real and virtual spaces, which span one axis in the continuum. **Mobility** is one aspect regarding the physical ability of MR Technology to move dynamically, free in space or in the other extreme to be completely restricted to a static location. **Temporal** aspects regard responsiveness of interfaces which can be real-time, synchronous but also delayed, asynchronous. **Collaboration** can be supported for multiple users, but can also be restricted to a single user. **Ubiquity** spans an axis between pervasive computing, also called ubiquitous computing, which means many computers per user, and monolithic computing, which means many users per computer, *e.g.,* former mainframe systems.

Development is considered to happen within this complex five dimensional continuum (Figure 2) for MR technology. Essentially, a MR designer and developer should consider the needs and aspects of the expected MR engagement based on the application area. This thesis concentrates on the development of MR technology infrastructure and on the integration as well as on the design of MR tools for enhancing urban communication processes.

1.3 Urban Communication Processes

City development practices emerge as one of the study fields for MR [171] in the growing research area of urban MR [104]. Novel MR tools allow one to tackle the root of all urban questions concerned with merging past, future and the present state of a city. MR users can envision and observe the existing environment while simultaneously augmenting it with virtual elements as stated by Basile *et al.* [11].

Urban projects involve multiple actors and urban changes require broader participation to minimize incertitude, share risks and adopt a more democratic approach to the city development process. Public authorities and urban specialists are obliged to work with additional actors to form power networks, bundling their efforts, as attested by certain scholars working on "urban governance" [118]. The involvement of new stakeholders, such as property developers, financial institutions, non-governmental organizations, and citizens representing diverse professional cultures, academic training, economic and social priorities, in the city development process, leads to multiple, insecure and fragmented power of decision and action. Management, conception, definition, implantation and financing of urban projects is therefore more difficult and raises important issues, like higher intricacy in decision-making processes, caused by integrating the new stakeholders into the planning process [58]. In general most aspects of urban planning, be they economic, political, social, financial, and environmental, imply risks. The interaction between them adds up to the complexity as a whole [15].

The new actors in the urban process are considered as full partners in the evolution of the city development process, leading from a linear, hierarchical scheme into a more collaborative heterogeneous and dynamic process. A better mutual understanding of needs, lifestyles and expectations is considered to enrich the projects, leverage appropriation, increase satisfaction and build trust [3]. "*The emerging culture of wider participation and negotiation in city-making*" [124], is engaged in a quest for appropriate responses to late modernity's social, economic, cultural and environmental challenges, which require revision of past development methods. Reflexive processes of modernization [16] and increasing entropy and complexity in private and public life around the world [12] entail concepts involving sustainable and integrated development, concepts that emphasize interdependencies based on transdisciplinary urban development methods.

Wider participation, including new stakeholders, in urban project processes raises questions on several issues concerning:

- Power games between stakeholders [20]
- Participatory processes and decision making [159], [133]
- Representation, discourse and rhetoric in urban communication processes [101]

Visualization media and its use in urban communication processes is in the focus of controversial discussions among urban specialists, as it is a powerful tool used to support and influence the communication process. It was found that using certain techniques "... *visualization through digital technology provided a common language for all participants*" [3], but according to Sanoff [147] it can be problematic in a diversified multi-actor environment. Subjective interpretation of representation media depends on the socio-cultural and professional background of each actor [160] and can imply ambiguities. However, several authors suggest that visualization is the key to public participation [83]. Ethical issues of using VR technology for representation are discussed by Brey [28], who sees the responsibility on the side of the application designer to inform the user about possible risks of misinterpretation. This makes sense for closed systems, but if the user is involved in creating or designing content, ethical responsibility must as well be her concern.

Concepts for describing and structuring individual human experiences, processes, states or behaviors in the context of VR or MR environments are being explored and developed by several fields of science. Seichter sees the research concerning the concept of presence as a key measure going beyond the technical concept of immersion [171]. MR is developing as technology advances and new channels, dimensions or qualities are recognized by concepts such as presence, and are considered for natural interface design, contributing to collective communication needs of urban processes. However, all media content (*e.g.* images, sounds, 3D models), interface design and actors have an impact on mixing urban realities using MR technology.

1.3.1 Problem Statement

The overall goal is to support urban processes at various stages of city-development by designing and developing MR technology, resulting in communication aiding tools and insight into their design.

A complex structure of negotiation phases (Figure 3) is established in the usual workflow of urban planning professionals to address urban issues.

A vast complexity of planning aspects involving multiple risks concerning the future of society need to be considered by the actors involved in the urban development process. In the IPCity project, a multidisciplinary team of scientists was engaged in a scientific development process to enhance urban processes using MR technology. Due to the enormous experimentation space spanned by the complexity of urban planning and city development aspects, collective effort is needed to minimize risks and consciously develop a sustainably bright future concerning all inhabitants on our planet, possibly increasing happiness [46].

The emerging culture involving new stakeholders in urban processes diversifies risks and an effective revision of communication methodology can minimize risks, so the key problem is to find communication methods serving within the experimentation space to aid positive development in the collective effort.

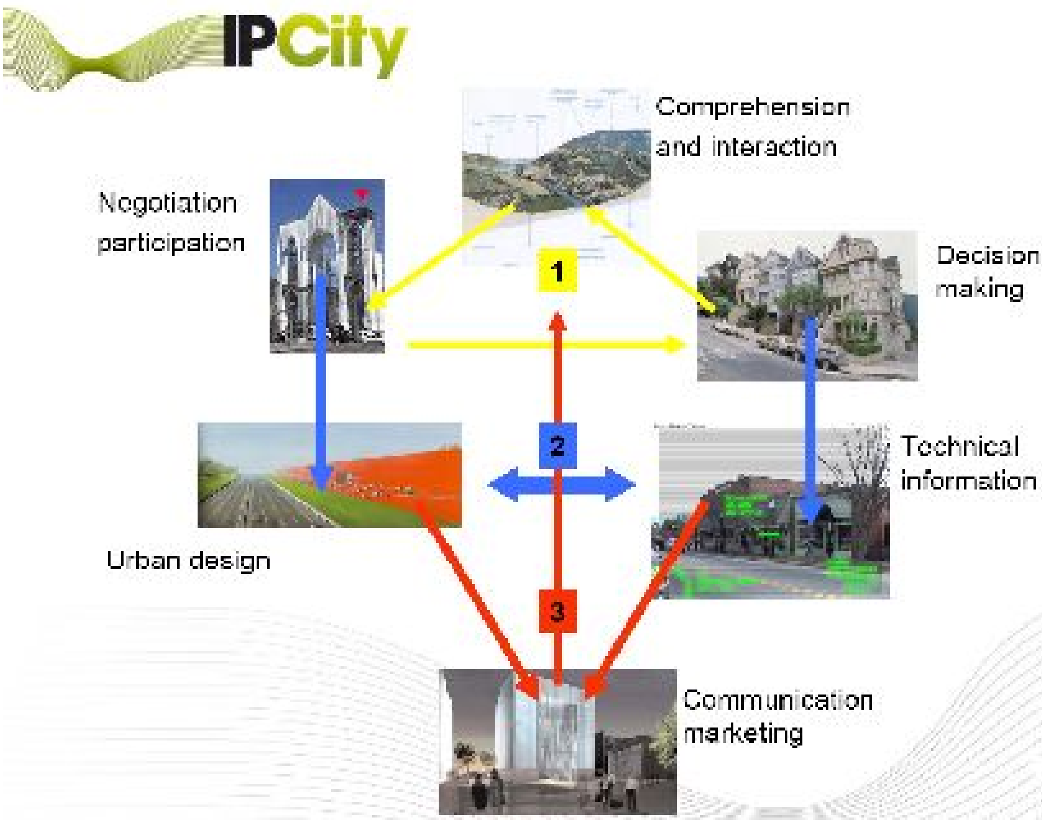

Figure 3: Negotiation Phases of Urban Planning (J. J. Terrin)

MR technology is considered a very powerful tool capable of assisting mediation by its user interfaces and the media content, both used for representation and communication purposes. As a result of integrating MR in the urban development process the **key issues** are:

- media content selection/generation
- interface design

In order to **prevent the misunderstanding** of media, destructive power games or manipulation between actors, the following regulating mechanisms may help harmonize mixing urban realities:

- pedagogic assistance
- filtering communication media
- moderation

1.3.2 Research Questions

In essence progress is about in-situ human-human computer-mediated communication aimed at aiding mutual understanding. The support of a wide range of user expertise without disregarding anyone, enhances the process of developing collective consciousness [11] about complex aspects and risks in urban planning.

"*We need to reverse the machine-centered point of view and turn it into a person-centered view: Technology should serve us.*" (D.A. Norman, 1993)

What we want to achieve is a harmonized interface design and insight to handle and create media content, with the purpose of enhancing urban processes. Since we are following the proposal of Avision *et al.*: "*To make academic research relevant, researchers should try out their theories with practitioners in real situations and real organizations*" [5], we are confronted by numerous dynamically changing and partly correlating factors, which simultaneously influence the experimentation space. This makes one aware that it is an enormous challenge to progress on serious real-world integration while measuring factors for proving basic theoretical concepts. "*Human-interface guidelines are often based on best-guess judgments rather than on empirical data*." [158]

The methodology chosen in IPCity is to work with technology probes [68] to motivate the co-design of MR-tools in participatory workshops arranged in real-world urban processes. Methodological qualities, most prominently experience, observation and intuition from all involved scientists and actors complemented each other in gaining insights and making practical progress.

Findings of related work in particular from Al-Kodmany who enhanced participation in a planning and design process, state that: “*Freehand sketching and the GIS were most effective for problem identification and brainstorming, while photo manipulation using computer imaging was most useful for exploring solutions to previously-defined design issues*” [3]. Urban planners, architects and designers use imagery to generate new form combinations and represent them by sketching [50]. This propelled the development of the MR application Urban Sketcher. The following questions were formulated to motivate engineering support and progress of MR infrastructure and tools by advancing Urban Sketcher and contribute to urban processes:

How can concurrently developed technology probes (MR tools and interfaces) be integrated and used to enable collaborative work in a joint workspace?

How can sketching tools be integrated with elementary tools for mixing urban realities?

How can communication between humans with a wide range of expertise, engaged in urban processes, be harmonized by utilizing MR technology without disregarding anyone?

How can handling and creating media content in a collaborative workspace be inspired and encouraged with MR tools, to enhance individual expression?

How can MR mediate mutual understanding leading to consent?

How can MR aid decision making in urban processes?

1.4 Contribution

This thesis reflects and contributes by reporting on technology and observations made during the development and evaluation of Urban Sketcher, an MR technology, created and continuously refined during 4 years of research in the IPCity project, concerned with mixing urban realities in several real-world urban planning scenarios.

Sharing individual visions using multimodal expressions allows actors to participate in the urban development process. Development aimed at achieving consent on diverging ideas, views or perspectives requires interaction, experience and flexibility from multiple actors. A shared digital workspace, Mixed Reality, functions as mediator. Naturally designed interfaces and tools aimed at aiding collaborative communication are integrated by Urban Sketcher and allow those involved to alter MR.

Common insight of all stake-holding contributors is inevitable, collaboration is needed in order to make progress towards achievement. In order to support natural communication aimed at optimizing communication bandwidth, the immediacy of place plays a central role. "*Since MR is grounded in the real world, it is natural to support co-located interaction.*" [167]

With respect for individual expression without disregarding anyone, all insights should be shared as a basis for further negotiation and discussion on problematic or diverging views. In a loop of collaborative experience and expression, progress can be made by gaining shared knowledge on more and more details of the topic, thus "*... create(d) valuable input for further planning sessions*" [168]. The evolving digital representation of a joined vision in MR can act as a common ground and mediate progress on urban planning issues.

Seam [71] optimized interfaces give access to tools mediating individual expression. One contribution is the development of hardware and software interfaces as well as tools for supporting the individual input to the collaborative workspace, MR. In particular in this thesis the emphasis is on sketching with a stylus or laser pointer, giving flexibility and moderation support in a collaborative situation (*3.3.3 Stylus / Laser Pointer Input, 4.2.2 Phantoms, Occlusions and Layers, 4.2.3 GPU Sketching and Painting)*.

Further contributions are the integration and management of various input and output interfaces (*4.2.4 Application Integration*). The output and unified feedback for all collaborators was designed to be rendered for a central common display which can be altered to five different representation modes along the MR continuum. Type of scene composition and spatial position, orientation and field of view can be adjusted by the interface and serve the collaborators as the focus for their work (*4.2.1 MR Views of the Environment*). In this way, the area of attention and the level of "*reality*" can serve as communication aids.

In summary, all the practical work is reflected in the configurable real-time MR application interface Urban Sketcher (see publications below) which was deployed outside the lab in real-world urban planning scenarios inside the MR Tent (*3.2 MR Tent*). In particular, the investigation looked into the possibilities of designing real-time computing environments which would afford effective eye-to-eye collaboration and permit individual expression and experience at various levels of expertise, without disregarding anyone in the natural communication process. The experimentation application Urban Sketcher contributes a platform with great configurability and interface flexibility, so numerous interaction situations can be and have been designed and evaluated.

The first publication on Urban Sketcher reflects early work on bringing the *Mixed Reality Laboratory* on site and gives feedback on a joined workshop utilizing the Urban Sketcher interface in the field:

Urban Sketcher: Mixed Reality on Site for Urban Planning and Architecture [150]

Mixing realities in the urban planning and design process outlines real-time interaction experiences. Mainly live sketching in an augmented scene was examined where users worked with creating and placing sketched canvas layers in the 3D environment. Spatial collages and transparencies were used to created depth with the virtual elements arranged in real-world construction sites.

Urban Sketcher: Mixing Realities in the Urban Planning and Design Process [151]

This MR Tent publication reports on a participatory workshop experience with MR technology deployed inside the specially designed MR Tent on an urban reconstruction site. The real-world planning situation engaged mixed groups of stakeholders, who collaboratively developed their visions of the future urban design on site. In the center of the process of mixing urban realities was the co-construction of a new urban district uniting two formerly separate towns.

MR Tent: A Place for Co-constructing Mixed Realities in Urban Planning [100]

The interface design and evaluation publication challenges criteria relevant for the natural progress on efficient exchange of information between humans and the computer using bimanual handheld interfaces to perform standard tasks in MR for urban planning.

Bimanual Handheld Mixed Reality Interfaces for Urban Planning [152]

The *Chapter 7 Discussion* reviews the initial research questions and suggests some answers on how communication can be inspired and supported by mixing urban realities using mixed reality technology.

1.4.1 Collaboration Statement

This thesis incorporates the outcome of research in collaboration with other researchers. The following lists gives an overview of the people involved and their roles in the development of Urban Sketcher.

1. Prof. Jean-Jacques Terrin is Professor for architecture at Versailles and runs a European platform of observation of urban projects. He contributed by professional insight into urban processes as well as many valuable contacts for involving stakeholders and realizing the on-site workshops.
2. Prof. Maria Basile, M.Phil. Sevasti Vardouli, M.Phil. Burcu Ozdirlik contributed city-development insight [11], [124] and the organization as well as analysis of the scenarios in urban planning workshops.
3. Prof. Reiner Zettl is an art historian and teaches in the context of urban strategies[8] at the University of Applied Arts in Vienna, he contributed discussions and workshop topics as well as design inspirations for the MR Tent.
4. Dipl.-Ing. Andrea Börner, a teaching architect, contributed by testing the interface and giving feedback on usability issues.

8 http://urbans.publick.net/1.html (27.09.2010)

5. Prof. Ina Wagner is Professor for Multidisciplinary Systems Design and Computer-Supported Co-operative Work and contributed by insight and guiding participatory design methodology [168] as well as developing an approach to the role of presence in MR [169].
6. Dr. Thomas Psik, Dipl.-Ing. Valérie Maquil, MSc. Michal Idziorek, and Mag. Lisa Ehrenstrasser contributed to the MR Tent design and developed the ColorTable [96] [97].
7. Mira Wagner, an artist, produced image content for the Workshops and gave design insight and feedback on using the Urban Sketcher interface.
8. Dr. Raphael Grasset contributed a CPU-based painting approach [52] and helped to design spray-can interaction. Also initial discussions on GPU-based painting helped the further development.
9. Dr. Hartmut Seichter and Dr. Andreas Dünser contributed insights on interface design in general, and discussions on the laser-pointer operated screen-aligned 2D interface in particular.
10. Prof. Gerhard Reitmayr contributed a model based tracking solution for the scout similar to the "*Going out*" [139] tracking. Furthermore he contributed OpenTracker [138] and insights on scene graph implementation issues.
11. Dr. Bernhard Reitinger developed the initial scout idea for interactive 3D reconstruction and wireless image acquisition [137].
12. MSc. Alessandro Mulloni implemented the first streaming solution based on the Live555 library for the scout.
13. Dr. Denis Kalkofen and Dipl.-Ing. Markus Tatzgern developed the scout further by integrating GPS and alternative tracking solutions like model-based outdoor tracking, which was originally developed by Prof. Reitmayr. They also assisted on GPU implementation issues and helped to generate and integrate 3D content.
14. Dr. Daniel Wagner contributed the Muddleware library [165], the natural feature tracking implementations [166] as well as many fruitful discussions.

15. Dipl.-Ing. Gerhard Schall contributed insights on next-generation field information systems for utility companies, providing mobile workforces with capabilities for on-site inspection and planning, data capture as well as knowledge on built surveying using outdoor AR [153].
16. Dr. Ernst Kruijff is one of the book authors of *“3D User Interfaces”* [27] and contributed with lively 3D user interface discussions.
17. MSc. Manuela Waldner contributed discussions on multi-display environments [170] as well as on quantitative evaluation and statistics.
18. Dipl.-Ing. Christian Pirchheim contributed the visual programming implementation interface for Muddleware [129].
19. MSc. Eric Mendez, MSc. Eduardo Veas, Dipl.-Ing. Berhard Kainz, Dr. Alexander Bornik contributed by assisting in solving implementation issues in the context of Studierstube.
20. Abert Walzer, Mark Doktor and Christina Fuchs contributed with administrative services.

1.4.2 Thesis Outline

Chapter 1 introduced the environmental context and the motivation for the work reported in this thesis. *Chapter 2* comprises a collection of related work. In *Chapter 3* the MR framework used for developing software and hardware is described with a focus on the MR Tent and involves infrastructure and MR technology. *Chapter 4* outlines details of Urban Sketcher, the interface application developed by the author in particular to enhance urban communication processes, thus enabling mixing urban realities. A summary report in chronological order on the use of Urban Sketcher in real-world workshops and events, embedded in urban processes to propel participation, is detailed in *Chapter 5*. In combination with a table-top model, two promising bimanual interfaces realized by Urban Sketcher, are evaluated using standard MR tasks in urban planning scenarios in *Chapter 6*. Finally *Chapter 7* presents discussions and future work in the context of mixing urban realities using MR technology.

Chapter 2

Related Work

This Chapter gives an overview of the standing of MR technology and research touching and influencing the process of mixing realities. MR technology is continuously progressing in its various dimensions mentioned in the section on *1.2 Mixed Reality Used for Mixing Realities.* The related work chapter comprises collected information on *2.1 Mixed Reality Technology* including subsections on *2.1.1 Scene Graphs, 2.1.2 Displays* and *2.1.3 Tracking.* This is followed by the section on *2.2 Interface Design* which gives an insight into the current development in the field and comprises subsections on 2.2.1 *Presence and Engagement* Concepts, *2.2.2 Collaboration and Participation A*spects and *2.2.3 Manipulation, Sketching and Painting* Work. More specific related work on MR involving urban aspects can be found in the last section of the chapter *2.3 Urban and Architectural MR.*

2.1 Mixed Reality Technology

Early visions of the computer in the 21st century are expressed by Weiser in the year 1995 [173]. The two surveys on AR of Azuma [7] [6] outline application fields and research done in the field of AR in particular. Another reference roughly summarizing current research on AR is the bibliography [2]. Recent trends in AR are outlined in the publication of Zhou *et al.* [179], which also proposes a roadmap for future work in the field. AR partly covers the MR continuum (see *1.2 Mixed Reality Used for Mixing Realities*). AV [134] is another part of the continuum. However, 3D user interfaces [27] are needed to enable interaction along the MR continuum.

MR technology requires software for representing virtual spaces and for merging them with the real-world. Scene graphs are the software basis for this purpose, and are explained in the next section. In the subsequent section various displays are described, as they are needed for displaying information, thus physically creating information cues. The tracking section comprises work on extracting spacial relationships of real-world objects, needed to synchronize and register real and virtual spaces of MR.

2.1.1 Scene Graphs

Scene graph APIs have become common tools for developing interactive 3-dimensional workspaces like MR scenes. They offer an object-orientated, structured approach and address complexity for developing graphical applications from a software architecture standpoint, [163]. Open Inventor (OI) is the toolkit proposed for handling application states and rendering the output. The scene graphs are rendered in real-time to allow fluent multimodal output and interactions. Today, complex MR scenes are handled by successors of OI. The scene graph used in this work is Coin 3D[9], others are *e.g.* Open SG[10] or OpenSceneGraph[11].

MR Scene

> The workspace, Mixed Reality, consists partly of the real world and partly of a virtual world. The MR scene is the 3-dimensional digital representation of MR based on a scene graph.

Once the MR scene is created and rendered, the resulting information cues need to be displayed to the recipient(s) on a hardware device, the display.

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9 http://www.coin3d.org/ (14.09.2010)

10 http://www.opensg.org/ (14.09.2010)

11 http://www.openscenegraph.org/ (14.09.2010)

2.1.2 Displays

The term display mostly refers to visual displays for graphical output, but is sometimes used for output devices in general. To be able to perceive the virtual information of MR, displays are needed as output interfaces. Individual, mostly egocentric displays, are usually head-mounted devices (HMDs) or CAVEs [37]. The virtual tea pot in Figure 4 is essentially visible through the stereoscopic optical see-through head mounted display of the user and is moved through space by the hand pointer. Note that the MR scene was rendered in the perspective of the observing camera to illustrate the synthetic visual cues (MR scene) perceived by the user wearing the HMD.

Figure 4: Real-time Mixed Reality viewed with a HMD

A limited field of view (fov) and restricted movement is common when working with HMDs due to current technological limitations. Another crucial factor is the restricted eye contact imposed by HMDs (Figure 4). Wearable displays were found to reduce eye-contact and seem unnatural in conversations [103]. Urban communication processes imply multi actor environments, where these restrictions introduce seams and have an impact on the communication process and limit natural information exchange.

A common view, the same perspective for all recipients, accompanying the workflow towards the tasks objective, is helpful for all coworkers. For MR there are displays available which can be designed to give individual or common views into the MR scene of the workspace.

Stationary MR displays are often used for common views. Eye limited display fidelity which enables a fusion of real and virtual worlds, indistinguishable for human perception is developed in the Allosphere [66] project at UCSB[12] with cutting-edge stationary display technology. The inner hull of the AlloSphere will be capable of displaying 360° stereoscopic scenes. This spherical Mixed Reality environment is aimed at simulating virtually real sensorial perception. The synthetic visual space is projected onto an almost spherical screen, which is ten meters in diameter. This three-story high MR laboratory concentrates on VR moving towards immersive qualities formerly only know in science fiction as the holodeck. An envisioned interface for the AlloSphere could be specifically designed to support the mixing realities process for interacting with the shared information space using laser pointers. A monoscopic display mode would allow unobstructed face-to-face communication while the spherical display configuration could deliver rich depth cues for colocated work regarding urban development in the center of the sphere.

Large flat displays are often used together with touch-based interactions. One commercial solution is the modular MultiTouch[13].

"*Design Considerations for Collaborative Information Workspaces in Multi-Display Environments*" are discussed by Waldner *et al.* [170]. In multi-display environments, MR boundaries [17] occur and introduce various seams. When designing interfaces in the context of multiple displays, the spatial, temporal or functional constraints imposed by the seams need to be considered.

However, the downside of very large and high quality displays is their weight and size restricting them to stationary use. Semi-mobile solutions can be moved and set up for use outside the laboratory. They comprise large-screen and projected MR displays, but also Spatial AR, where the real part of MR is a specific object, the surface of which is directly modified using projected imagery as out-

12 http://www.ucsb.edu/ (27.09.2010)

13 http://multitouch.fi/(27.09.2010)

lined in the book by Bimber and Raskar [24]. Another class of displays allowing a common view for a small group of people is mobile and can be hand held during use.

The same visual stimuli are delivered by a common view to the individual co-workers engaged in mixing realities. An unobstructed common view supporting simultaneous eye contact is technically easily implemented at present using a monoscopic display. Cutting-edge auto-stereoscopic display technology displays three-dimensional views unobstructed simultaneously for multiple viewers[14]. However, a common view can be used for visual feedback of the workspace for awareness and direct interaction response.

For viewing the visual output, there are two fundamental classes of views ranging from exocentric which means “looking at” and places the viewer above the displayed situation to egocentric which means “being in” and places the viewer in the displayed situation similar to the viewing perspective of the human visual system we are used to for seeing our environment. For application in urban planning the whole range of views are considered for providing multiple perspectives of or in the urban MR scene which can be instrumental for collaboration and need to be selected or changed interactively for viewing the workspace and achieving certain tasks. An exocentric view gives a summary, a overview, whereas an egocentric viewing perspective can highlight special areas of attention typically located at street level, *e.g.,* outdoors in a city, oriented towards the surrounding. Directing the view on a shared display requires human input to support navigation and provides a common dynamic perspective of the workspace in the mixing urban realities process (also see *2.2.3.1 View Manipulation*).

2.1.3 Tracking

One key prerequisite for technically combining realities is the knowledge about spatial relations between real objects, so the virtual dimensions and objects can be registered and synchronized. Tracking techniques are used for extracting this information from the real world.

For user tracking (head tracking) or viewpoint tracking (camera tracking) and object tracking, there are many solutions for indoor MR applications based on fixed installations. No optimal solution

14 http://www.holografika.com (27.09.2010)

has yet been proposed for 6-Degrees of Freedom (DoF) outdoor tracking in unconstrained environments, going beyond the precision of GPS, leading to a more robust and precise localization required for outdoor MR scenarios. Currently GPS precision can be optimized with an assisting online data connection to a reference server. Good signal strength for GPS is achieved when used in open spaces, but quality deteriorates significantly in urban environments. Shadows from buildings and signal reflections reduce precision of GPS position estimates. Orientation sensors in urban environments also encounter negative influences, as inertial sensors accumulate drift offsets and magnetic sensors are disturbed by local magnetic fields. Precision of the mentioned trackers for location tracking in urban environments is not yet sufficient for seamless AR.

Well known indoor solutions are often based on either one of these approaches: Infrared Optical Tracking[15] needs stable controlled lighting situation and is invariant to magnetic fields, Magnetic Tracking[16] needs stable controlled magnetic environment and is invariant to light changes, Ultrasonic Tracking[17] is invariant to magnetic fields and light changes, but always needs an active transmitter and receiver, Inertial Tracking[18] is inaccurate over time and drifts requiring recalibration, Marker Tracking [78] needs a rather stable lighting situation and physically visible markers, and Natural Feature Tracking [166] also needs a stable lighting situation and good contrast in textures. Natural feature-based computer vision techniques allow the move away from fiducial markers towards the use of unmodified, every-day objects such as printed paper maps or event brochures as tracking targets.

In order to improve tracking, assisted GPS can be combined with visual tracking methods [140]. Another approach to increase precision, continuity and stability is the integration of multiple sensors using a Kalman filter [154] for sensor fusion and signal filtering. Some application scenarios require seamless tracking, although different tracking technologies are used. Ubiquitous tracking solutions deal with these kinds of issues [117].

15 http://www.ar-tracking.de/ (02.10.2010)
16 http://www.polhemus.com/ (02.10.2010)
17 http://www.intersense.com/ (02.10.2010)
18 http://www.xsens.com/ (02.10.2010)

2.2 Interface Design

Not only the field of research developing a concept of presence is conscious of the underlying metaphors and principles, but also the human computer interaction (HCI) community seems to refocus in order to start *"reflecting human values in the digital age"*. Serious thoughts on *"whether its methods remain relevant"* are articulated, realizing that *"the challenge confronting the field now is to deal with issues that are much more complex and subtle"* [156]. Computer technology is melting borders, enlarging the potential interaction space to ubiquity. It is not only the human individual anymore, but the human as a part of society interacting at various levels with ubiquitously networked and mixed realities. New questions are about qualitative processes and potentials rather than only about quantitative data.

According to Don Norman: "*Interaction design is still an art form. The practice of ergonomics is a rigorous engineering field.*" [120] Ergonomics always play a role when interfaces are designed for interaction, they provide aspects concerning the health of engaged humans.

As identified in *1.3 Urban Communication Processes,* ethical responsibility is needed when designing interfaces for urban processes. Ethics can be a base for discovering common values. This needs constant reflection and refinement in order to advance the values lived and experienced. The value sensitive design methodology (VSD) is being developed to help incorporate value-sensitivity into the design of computational systems. "*Importantly, by evolving the design methodology to place an emphasis on the discovery of values we can derive system designs that reflect the values of the people they are meant to serve rather than the values of the system designers.*" [39] Ethics and responsibility are important in "*HCI for the Real World*" going beyond the constricting burdens subliminally imposed on the design profession by the cooperative world. "*While this paper has focused primarily on the social position of the designer within the relationships between HCI and industry, it must parallel the development of a culture of self-critique that will enable the creation of new forms of subjectivity and alternative visions of the future.*" [85] Interface designers are challenged to discover and integrate values of the people into their work and show ethical responsibility by progressing social ergonomics.

In the opening plenary of the leading HCI conference CHI2009 it was stated that: "*... it's time to study social ergonomics as the design of workplaces and systems that fit the natural social capabilities and inclinations of workers/users.*"[19] Summarizing the closing plenary: "*Design is about people.*", "*Intuition and common sense should be high on the agenda.*" and "*... the essential power of design is in integration.*"[19] So the direction of interface development is to integrate social aspects into usability and design, while using common sense and intuition. The special interest group workshop of the conference discussed on which methods to use for user experience evaluation [122].

MR usability studies are outlined in the tutorial of Billinghurst [23]. The kind of previously performed studies described isolate specific scenarios, where often few conditions are compared, *e.g.* AR vs. VR. Elaborate analysis and measurements lead to simple insights like "*AR is faster*". In IPCity we move out of the lab into the field, where the experimentation space is very large, challenged by the highly developed communication culture present in urban development processes. The aim of the work is to enhance these real-world conditions with social HCI aspects. Perhaps user-centered design (UCD) [81] can satisfy fundamental user needs as discussed by Keinonen, if ethics provide the basis for developing user protection and appreciation conditions. User-centered participatory design of MR Technology development in IPCity learned from related work and was strongly influenced by workflows, common in urban renewal processes concerned with urban development issues.

"*We must avoid the trap of only creating what usability can measure*" [38]. The survey of Hinckley *et al.* [63] concentrates on spatial design issues from a large body of work and aids inspiration for interface design. The concept of *affordance* and *ability* developed by Gibson [48] was seminal for ecological psychology focusing more on questions concerning "how" information is constructed. "*An affordance relates attributes of something in the environment to an interactive activity by an agent who has some ability, and an ability relates attributes of an agent to an interactive activity with something in the environment that has some affordance.*" [53] For Gibson the environment is important looking at "what the head is inside of" which is an alternative to looking at "what is inside of the head" and information processing theory. Norman also uses the term affordance, but

19 http://www.chi2009.org/Attending/Program.html (02.10.2010)

believes that it results from mental interpretation based on past knowledge and experience applied to perception. "*... the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used.*" [119] Differing believe and theories on perceptual learning and on how information is constructed will further challenge science. The author believes that ecological psychology attempts to study the part of this universe which is relevant, in particular in the urban context for information transaction formed by evolution and also takes into account the environment and all living beings and their reciprocity. Adapting the environment by designing affordances of things to the actors' natural communication and interaction behavior and reducing learning seems to be beneficial for their ability. Adaption of the actors' ability by learning new communication and interaction behavior with natural affordances seems to be beneficial for the environment. Looking at the interdependence of affordance and ability natural mappings (*1.1 Evolving Live Communication Technology*) are considered to be beneficial. Natural design of interface affordances is intended to enable the actors to interact with information and the environment containing it more intuitively.

Reflection and intuition in this work compromises for incorporating established workflows, natural affordances, support for a wide range of expertise without disregarding people who engage in mixing urban realities. "*Some tools and techniques better suit augmented reality … development of AR interfaces ... should focus on balancing and distributing features between the AR interface and other interactive media so that they all can be used within a single seamless augmented workspace.*" [130] Social, ergonomic and natural interface design was used during the usability work for developing a single seam optimized workspace in this thesis.

General directions and influences for designing interfaces were outlined. The following subsections are about 2.2.1 *Presence and Engagement* concepts, *2.2.2 Collaboration and Participation* aspects and *2.2.3 Manipulation, Sketching and Painting* work.

2.2.1 Presence and Engagement

Schubert *et al.* state that: "*Cognitive processes mediate the impact of immersion on the development of presence*" [155]. This roughly outlines what seems to happen when perceived stimuli are processed – experience. The concept of presence is manifold - among the multiple dimensions of presence that have surfaced in research, there are at least spatial presence (*e.g.*, perceptual immersion, sense of being there), sensory presence (perceptual realism) and social presence (co-presence). The concept of presence has been developing over a decade, mainly focused on the effectiveness of virtual environments. Mental user states in response to VR are described. Most research on presence is done in controlled purely virtual environments under strict laboratory conditions.

"*The sense of presence - is a subjective experience and only quantifiable by the user experiencing it.*" [155] The presence concept aims to structure and accumulate subjective quantified experiences mainly based on precisely designed and dispensed stimuli. The s*ense of presence* is the psychological phenomenon experienced as a sense of "*being there*" [136], [143], [60].

In general it seems to be difficult to find a uniform definition of presence, as aspects and influences are vast and highly complex. Everyone involved seems to have her own definition of the term. The authors definition of the term "presence" is:

Presence - the art of being there, but not really.

Presence in the context of mixing realities adds even more to the already vast complexity. In contrast to traditional research on presence, the phenomena considered for mixing realities have communication and the real world as essential properties. "*On the role of presence in mixed reality*" by Wagner *et al.* [169] marks the beginning of new research by recasting the traditional presence construct as a subjective, multifaceted experience.

Real-world application of mixing realities with the idea of presence in mind opens the door for new challenges in research as the environment intrinsically has a high fidelity due to the integration of real-world information cues which are not always fully controllable. Challenges are a vast amount of additional influential factors when considering mixing realities and the individual human experience, since the real-world aspects add to the experimental setting and can not be controlled in order to be separately studied as in mainstream presence research. In the research project IPCity presence is considered as: " *… the perceptual illusion of non-mediation*" [92].

"*There is no universally agreed definition of presence, however researchers broadly agree that it is a complex multidimensional experience consisting of a combination of sensory data and cognitive processes [143]. As a starting point however [44] highlights two useful conceptualizations relating to tele-presence:*

- *Forward presence: when a person is taken to a remote location. e.g. to control a bomb disposal robot*
- *Backward presence: where an experience is brought to the user, e.g. a location in Second Life.*

The combinatorial power of multi-space environments addresses a much wider variety of situations to be included, leading to a better match for the cultural-ecological study of urban environments such as that considered in IPCity." [167]

MacIntyre *et al.* recognize that the interpretation of presence in an AR/MR context is very narrow, and suggest extending the concept by *aura* and *place e.g.* significance of a certain place which possibly add new aspects to the concept of presence. They call this more general concept *engagement* [94]. The author adopts engagement, as the user's sense of emotional engagement is an element in the mixing urban realities process, thus people who actively take part, contribute and interact "*engage*" in mixing urban realities.

2.2.2 Collaboration and Participation

Co-presence naturally leads to collaboration. Collaboration is about socializing with the real-world and staying in touch. The summary on the 20th anniversary of the computer-supported cooperative work (CSCW) community found that the field is divided into a technical part and a social part with the need to improve interaction between the two [74]. Emphasis is less technical but more on social publications in the field of CSCW.

Collaboration

Working together with two or more people, joining efforts.

Learning from the CSCW community interfaces reducing seams relate to minimizing cognitive discontinuity, as explored in the work of Hiroshi Ishii [69]. The seamless design interface study uses HMD's to augment the view of collaborating users seated across a table [84]. Well-known collaboration supporting interfaces are tangible interfaces [72]. A collaborative tangible tool is the MagicMeeting, where a round "cake platter" in the center of collaborators is used to orient virtual artifacts [135]. A round table, an established real world tool, was tested with MR technology to "*... enhance round table meetings*" [111] in collaborative architectural and urban planning with the result that "*...feedback from end user tests is positive*" [111]. Handheld displays were used for collaborative design [141] by Rekimoto.

Table interfaces support face-to-face collaboration and provide a MR workspace for real and virtual artifacts. In addition direct interaction with the MR scene is possible using tangible objects. For designing collaboration interfaces currently handheld and projective display's seem to better support natural communication among users, as HMD's introduce seams (2.1.2 Displays).

Work on remote collaboration can be found in the telecommunication literature summary on remote and face-to-face communication comparison. Communication issues concerning remotely mediated conversations are discussed by Abigail Seelen [157]. The publication of Heath and Luff states missing social cues in mediated remote collaboration [59].

Wider participation is one of the trends in urban planning (see *1.3 Urban Communication Processes*). King *et al.* suggest visualization as the key to effective public participation, because it is the only common language between participants with varying expertise and experience possibly leading to co-design [83].

Participation

Similar to collaboration, but higher individual responsibility, commitment and engagement in taking part.

In 1991 a now widely used concept *"Communities of Practice"* (CoP) [175] was introduced. It stands for groups of people who share the concern and passion for something they do and learn doing. Building and supporting such groups should be the prime goal of participatory technologies as used for mixing urban realities [168].

In fact, MR can be created by re-purposing applications designed for single users to collaboration of co-located users through social sharing [112]. Since both social and mobile computing are becoming increasingly popular as new styles of human-computer interaction, they contribute as ubiquitous collaborative interfaces to shared information spaces, facilitating MR in a remote manner. Former spatial borders are being blurred by new technology enhancing communication, featuring social and mobile computing.

However, although mobile devices override physical space and introduce a densely growing communication bandwidth between people, face-to-face communication is vastly richer and cannot be substituted by technology, due to a lack of social affordance. This is especially the case for collaborative situations where effective live exchange of information takes place, and controversial discussions aim at laying out different points of view for consolidation. Seams in collaborative interfaces change the nature of collaborators communication behavior. For instance, remote collaborations mediated by video streams are "*... introducing certain asymmetries into the social interaction between users*" [59]. Abigail Seelen found in her remote conversation experiments that: "*There appears to be something critically different about sharing the same physical space ...*" [157]. Due to the seams introduced by the mediating technology, remote collaboration is not as rich in cues and therefore not as effective as face-to-face collaboration, this guided interface design choices of the thesis author for optimizing mixing realities.

The input of information into the collaboratively perceived workspace involves individuals supported by MR tools, which enable manipulation, sketching and painting in the MR scene.

2.2.3 Manipulation, Sketching and Painting

Manipulation in large MR scenes involves travel and navigation in combination with tools to alter the scene at the desired location. Common tools allow interactive change of object properties in the MR scene. Properties like position, orientation and scale are prevalently changed. Related work on the more particular altering of the appearance by painting or sketching objects is summarized after the view manipulation section.

2.2.3.1 View Manipulation

For video-based MR, it is usually assumed that physical camera and display are either stationary or move together as one rigid combination. In contrast, there is a large body of work on travel and navigation needed in the field of VR. Travel and navigation in immersive VR have been studied by Bowman *et al.* [26] [25] who identified that reducing the disorientation of the user in a pure egocentric setting is challenging. The disorientation issue is also present in desktop VR setups were constraints alleviate navigation [57] [49] [55]. Tools like Navidget [54] [43] aim at reducing the mental load on the user. Multiscale 3D Navigation [105] puts an emphasis on seamless navigation between egocentric and exocentric views on desktop VR setups, building on previous work of HoverCam [82] used for 3D object inspection, just like StyleCam [32] or ShowMotion [33], which resort to predefined motion paths to control the observing camera. Mackinlay *et al.* [95] also compute the camera animation path from a user-selected point of interest.

Early work by Ware and Osborne [172] introduced the "*eyeball in hand*" metaphor in VR. This approach required a mental model of the scene, because it did not provide any direct visual feedback. McKenna [107] suggests to provide a video-augmented scene on a mobile display this could be a WIM [162]. Tangible navigation support with a 3D map was suggested by Haik *et al.* [55]. The Rockin' Mouse [8] and trackball-mice [73] are hardware solutions for controlling more than 2DoF and were evaluated in the context of 3D interaction partly for bimanual use. Bimanual interaction, using only mouse and keyboard for desktop 3D environments, has been studied by Balakrishnan and Kurtenbach [9], where the non-dominant hand controlled the virtual camera while the dominant hand was used for manipulation tasks.

2.2.3.2 Sketching and Painting

Sketching is a broadly used term often involving a pencil or stylus for visualizing thoughts or ideas on, *e.g.,* a piece of paper. In the context of new technology, the medium for creating and transporting the sketch is not limited to paper anymore. Although the qualities provided by pencil and paper for sketching are difficult to replicate, attempts are made to create interfaces for sketching and painting, with digital tools. In this thesis sketching is understood as a fast and rough approximation. This can be the creation of an object in the MR scene or an artistic drawing (sketch) on an object, *e.g.,* by altering the texture of object in the MR scene.

In the work on "I*nteractive Sketch Generation*" [76] and "*Interactive Technical Illustration*" [51], sketches are generated from preexisting objects, highlighting the objects silhouette and distinctive contours. 3D sketching, as described in "*3D Sketching with Profile Curves*" [89] is used for rapid prototyping, as users can intuitively create and model arbitrary shapes in 3D space. The ArtNova system [45], was especially created for 3D model design. It enables the user to apply textures directly on the 3D surfaces. Modeling can be done interactively with the support of haptic feedback to the user. Another solution using haptic feedback to support the users senses is "*DAB*" [13]. The main focus of the work is on supporting artful painting with 3D virtual deformable brushes. "*CavePainting*" [80], aims at providing tools for 3D art creations in a CAVE workspace. Further development led to tools for realizing scientific visualizations in VR [77]. A simple interface for painting allows children to explore painting textures with the I/O brush [146] [145]. In the center of the brush a small camera is used for taking arbitrary texture samples which are used for drawing on a screen.

"*Texture painting from video*" [67] uses image warping to acquire textures from a live video of the environment and match them on a 3D model of the environment. The texture mapping and warping is done in real time, thus reflecting dynamic changes to the texture of the 3D model. The idea of painting on virtual 3D surfaces was first identified over a decade ago, for example consider [56]. More recently, dynamic ShaderLamps [10] have been introduced as a tool for projector-based MR painting. Similarly, projector-based dioramas are used for architectural simulation in [93]. Grasset *et al.* [52] present an approach for video see-through MR painting loosely related to ShaderLamps.

To accelerate beyond conventional CPU based painting, the parallel processing capacity of the GPU are used for advanced 3D surface painting algorithms. The features of "*Painting Detail* " [34] are texture frequency based atlas generation and seemingly unlimited texture resolution for real-time painting. "*Octree Textures on the GPU*" [88] is another GPU painting implementation which uses an efficient and convenient way of storing undistorted data along the mesh surface. "*Multiresolution GPU Mesh Painting*" [142] supports quad-based real-time texturing, sculpting, smoothing and multiresolution surface deformations.

Painting and sketching imply texture manipulations which are computation intensive. In particular the simulation of sketching with a pencil on a piece of paper or on a sculptured surface requires a high sampling rate (~100Hz) to be able to capture enough details of the movement. The modified texture gives feedback to the user who is used to immediate feedback at perception-limited speed. Related work offers several solutions for texture modifications of 3D objects optimized for particular features often with specialized data structures. For achieving maximum speed, GPU texture manipulations are used. The data communication between CPU and GPU needs special attention in design, as this bottleneck can slow down operations when working with large scenes containing several transfer intensive data structures. However, urban planners, in particular architects, communicate with quick sketches to envision developments in urban spaces.

2.3 Urban and Architectural MR

Mixed groups of stakeholders can explore the complex societal and other implications of an urban planning project at early project stages and aim to avoid planning mistakes affecting investors, technical specialists and citizens. Environments for urban and architectural planning and education have repeatedly been the topic of human computer interaction research [30] [70] [128] [164]. Tabletop interfaces are popular for this area of application, as they accommodate architectural scale maps and models commonly used in architectural communication, and facilitate tangible interfaces. Specific related work on MR involving urban planning aspects can be found in this section. The overall goal of the urban planning process is consent, which requires the integration of many different points of views on a reconstruction site. The section on *2.2.2 Collaboration and Participation* lists a collection of related work involving support for planning and negotiation with tools for collaborative work. *2.2.3 Manipulation, Sketching and Painting* comprises work related to altering the MR scene in various ways. Al-Kodmany [3] found visualization techniques for enhancing public participation useful.

Tables with architectural scale maps and models are established tools in architectural discourse, enabling an observer to quickly grasp an overview of the planned design from an exocentric viewpoint. Interactive tabletop displays with MR capabilities and tangible user interface approaches have been developed to facilitate architectural education and also design negotiation [79] [70] [164] [100]. In “Architectural Anatomy” [42], the structural skeleton of a building was augmented. Neumann *et al.* [115] describe Augmented Virtual Environments combining virtual models with live video textures, mainly for surveillance applications. Lee *et al.* [87] describe an MR environment for 3D modeling and texturing. MR tabletop interfaces aim to combine the advantages of MR and collaborative interactions. They mostly use HMDs, showing an individual perspective of the scene to the users. However, HMDs limit collaboration to some extent, as eye contact and the field of view are restricted. Interaction is based on hand gestures or physical objects. The systems support the creation of geometries, architectural 3D scenes or building forms [111]. Other types of tabletop interfaces use projections and multiple screens to visualize the scenes that are created [100]. The Luminous table [70] is an augmented reality workbench integrating multiple forms of physical and digital representations, such as 2D drawings, 3D physical models and digital simulations, which are all on the same table surface. More specific architectural topics are addressed by Urp [164], a physically based workbench that allows users to study light properties and flows of an architectural scene, and by Illuminating Clay [128] a system for altering the topography of a clay model in order to design and analyze landscapes. The results of these modifications are constantly projected back into the workspace. The Envisionment and Discovery Collaboratory [40] uses computer simulations and tangible objects to represent elements of the domain, such as a simulated bus route.

Urban and architectural MR involves related work from diverse fields for integration. Implementation of infrastructure and interfaces enable human interaction using communication tools in one workspace. Developed mixed reality technology used for mixing urban realities is part of the next chapter MR framework.

Chapter 3

MR Framework

This chapter outlines the influences on MR of technological and human aspects regarding the development for mixing urban realities. The section *3.1 Software Infrastructure* comprises implementations used for developing MR tools and applications. This is followed by section *3.2 MR Tent* which documents design stages, assembly and deployment of the enclosure allowing researchers to move the physical workspace out of the lab into the field. The final section of the chapter *3.3 MR Technology* subsumes developed technology components.

The MR framework is the engineering basis integrating input and output technologies. These are hardware and software components combined to form infrastructure and interfaces for multiple users of MR.

In the sense of ubiquity, the influences concerning MR are illustrated in Figure 5 from a high-level perspective. The illustration gives a coarse overview of interconnections between the technology and the senses and sensations concerning experience and expression of the individual human engaged in MR. The first section in Figure 5 represents the user and her consciousness in the current

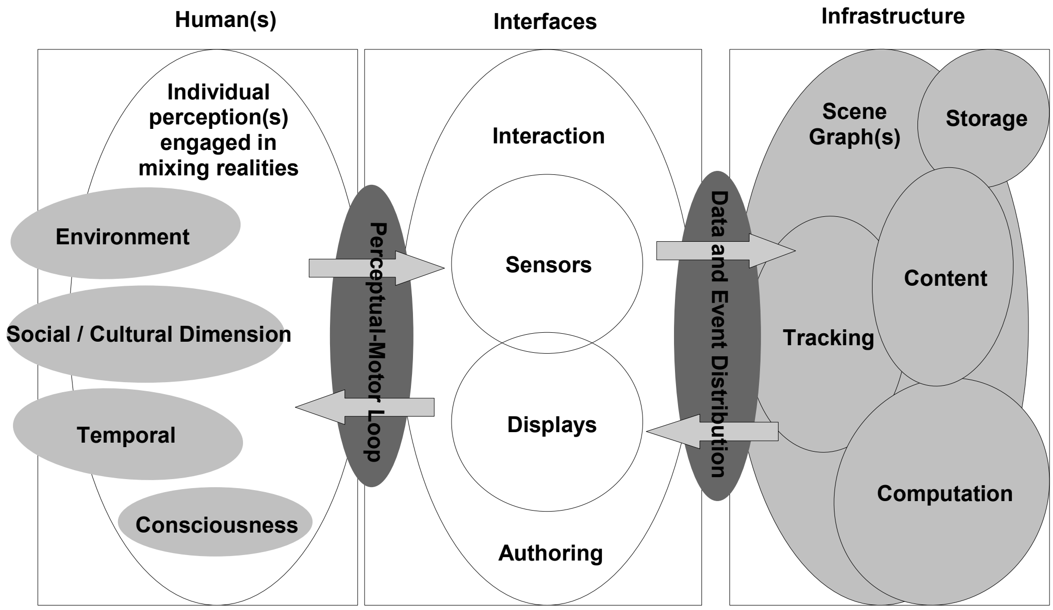

Figure 5: Influences on MR

context, influenced by temporal, cultural and social aspects. The current state of the MR user is studied and analyzed by concepts called presence or engagement (see *2.2.1 Presence and Engagement*). A conventional human-computer interaction loop demonstrates that humans, interfaces and infrastructure each have very complex aspects influencing each other.

The second section of Figure 5 shows that interaction between human and machine is possible through hardware, allowing software to form interfaces for displays addressing senses, thus leading to experiences. Interfaces also supporting sensors for feedback channels enable individual users to engage and integrate their expressions, thus allowing collaboration (see *2.2.2 Collaboration and Participation*). As defined in *1.2 Mixed Reality Used for Mixing Realities,* this process is called mixing realities when working in a shared workspace. Authoring stands for moderation and harmonizing of media content, possibly involving rules and roles to encourage and support development within mixing realities processes.

In contrast to traditional user interfaces, mixed reality user interfaces are typically not limited to one or two particular devices, but rather use a large variety of individual devices supported by the underlying infrastructure, as abstracted in the right section of Figure 5. Thus mixing realities on an arbitrary scale is only limited by the capabilities of the underlying infrastructure. Integration and the application of open interfaces are essential for large-scale collaboration. The infrastructure allows to dynamically route the exchange of information not only between users, but enables 1-to-n as well as n-to-1 communication. Several modalities can be supported by interfaces made from hardware and software components. These tools enable and enhance communication processes. A data and event distribution system connects interfaces and infrastructure. An efficient way of handling states, data flow and rendering is the use of scene graphs (see *2.1.1 Scene Graphs*) for MR. They can be utilized to manage the input, output and processing of data and events. Tracking (see *2.1.3 Tracking*) is needed to extract the location of real-world entities and therefore enables augmentations known as AR or AV. Content is needed to represent the virtual part of MR, and storage addresses temporal issues like persistence and documentation of history. Computational algorithms for rendering and scene graph traversal are needed as well as for computer vision tasks, possibly involving tracking, content creation and content manipulation.

The overview diagram presents interface and infrastructure categories which are needed to create urban MR, an information space that "lives" around the users. The requirement for developing the technology-integrating framework is to provide all the necessary components needed by MR applications. These are used to create tools to support the design, authoring, moderation and evaluation of collaboratively created and arranged content in a unified workspace relying on user interfaces with natural design for efficient interactions.

Clearly the MR interface regulates what the designers and other users can do. Abilities can be limited but also extended by MR, depending on the interface design of the application. Good, natural interface design has a high degree of affordance and supports a wide range of user expertise without disregarding anyone, therefore careful design aids the process of developing collective consciousness about the common goal, involving complex aspects and risks in urban processes.

Interface design has extensively been experimented with in several cycles involving a multi-disciplinary team of scientists and real-world urban situations, summarized in *Chapter 5 Workshop Experiments* and *Chapter 6 Bimanual User Interface Study*.

From a technical point of view, enabling expression and experience in mixed reality environments for mixing urban realities requires a multi-layer approach:

- Firstly, the provision of the general hardware and software infrastructure and services to realize MR systems.
- Secondly, the provision of higher-level tools for authoring MR environments and supporting the realization of MR user interfaces with respect to design.
- Thirdly, the development of the actual MR application(s) integrating application-specific features and tools for interacting with a unified workspace.

The software infrastructure used for MR system development is described in the next section. The subsequent section, documents the development of the physical workspace, the MR Tent and the resulting MR technology of the development process.

3.1 Software Infrastructure

The chosen software infrastructure serving as the basis for developing MR tools and applications for urban planning and reconstruction was a new design of Studierstube[20] by the development team in Graz, in 2006 this was version 4.0 (growing stable). Specific requirements of the application field evolved, as *technology probes* [68] were deployed in real-world scenarios as outlined in *Chapter 5 Workshop Experiments*. In general, a high flexibility, extensibility and AR capability was a major demand from the beginning of the project.

Figure 6 gives an overview of the Studierstube architecture and the information flow employed. This will be explained in more detail in the next three sections, which concentrate on Studierstube, OpenTracker (OT) and OpenVideo (OV). Details are given of the basic software infrastructure components and the development work by the author to enhance functionality.

20 http://studierstube.icg.tu-graz.ac.at/ (02.10.2010)

3.1.1 Studierstube

Studierstube is an extension of OpenInventor[21], a scene graph rendering library. The documentation of Studierstube is available online[22]. In the following, a brief summary will outline components needed for realizing a simple application for video augmentation with Studierstube. Platform independence means for Studierstube that Windows and Linux are supported for most common features.

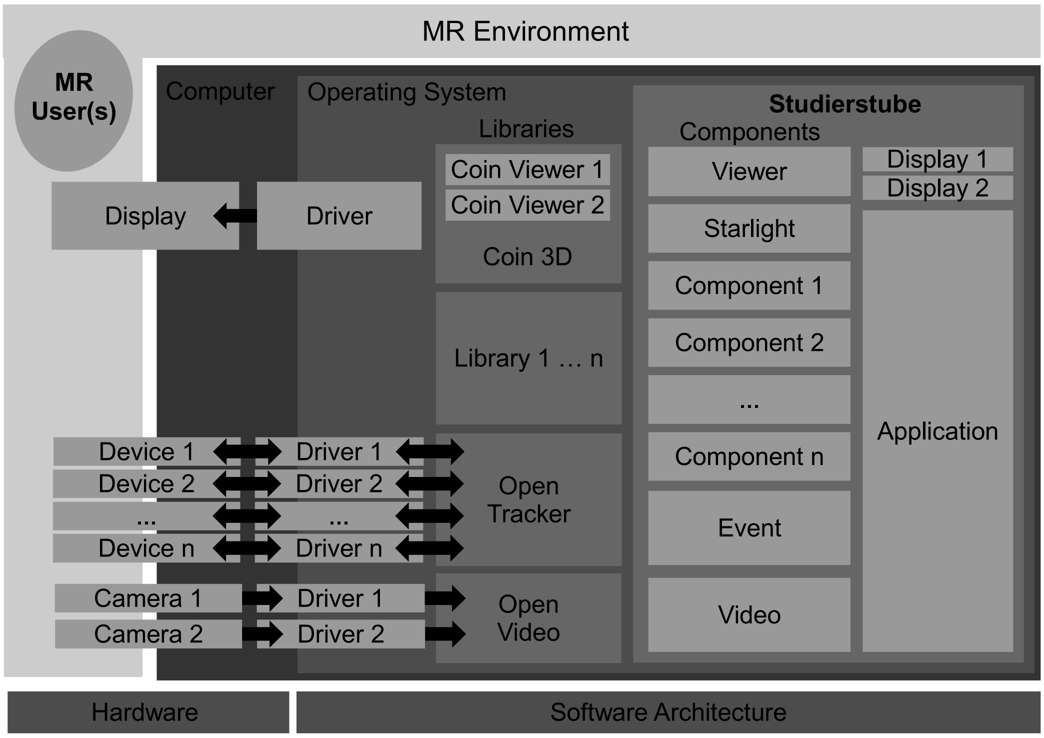

Figure 6: Studierstube Architecture and Data Flow

In Figure 6 the basic architecture of Studierstube and the main information flow between the components are visualized. The MR environment in the figure is the space in which the user(s) interact with MR, thus using hardware such as various devices, cameras and displays. The software translates physical values to and from the hardware. Drivers are low-level translators for this process. On a higher level, various libraries refine the data from the drivers. Essentially, Studierstube sits on top of the scene graph library Coin 3D, OT and OV. Studierstube is designed to integrate components and applications for supporting manifold scenarios. The basic components of Studierstube are:

21 http://oss.sgi.com/projects/inventor, http://doc.coin3d.org/ (02.10.2010)
22 http://studierstube.icg.tu-graz.ac.at/documentation.php (02.10.2010)

- **Kernel** always needed, as it loads all the components which are scripted in the configuration file.
- **Viewer** is an essential component which loads the respective windowing libraries for rendering the display(s) and graph(s).
- **Event** is needed for exchanging tracking data between Open-Tracker and the scene graph.
- **Video** is needed for receiving image data from OpenVideo.
- **Starlight** is a toolkit with useful nodes for the scene graph.
- **Components 1…n** are custom components which can be used to create further libraries.

The application in Studierstube represents the instance to manage interfaces between the different components and can realize interaction logic. Basic scenes can be created by using simple Open Inventor script files, *e.g.,* scene.iv. More complex interactions often require implementation in C++ within the application. In general it is a good idea to implement as much as possible in components, as they are more versatile than applications.

The integration of OV into the Studierstube MR framework is the basis for video augmentation, where the camera images are displayed in the background of the scene and the rendering is done from the camera's perspective and blended on top of the video background, thereby fusing real and digital space. The exact registration of both spaces is crucial for a seamless mixed reality experience. Position and orientation of the camera is gained from tracking and available from OT. Other parameters are usually static and defined in an initial calibration step.

3.1.2 OpenTracker

OpenTracker (OT) [138] provides an abstraction layer for data and event distribution and allows applications to be developed independently of the utilized tracking technology. Tracking data is either acquired directly from a hardware sensor or it is computed from video images by computer vision algorithms and then made available in the acyclic-graph of OT which is designed from an XML configuration file.

OT-supported tracking devices and frameworks are manifold. Most important for this work are the following preexisting tracker nodes:

- **Network** allows transmission of tracking data between computers.
- **ARToolkitPlus** allows single and multiple fiducial marker tracking based on AR-Toolkit [78].
- **ART** allows precise indoor infrared optical tracking[23].
- **Isense** allows the use of inertial sensors[24].

Other type of nodes in OT are the transformation, merging and filtering nodes which are used extensively to combine and refine tracking data.

The existing transformations were extended by an **EventDynamicVirtualTransformNode**, which allows dynamically changing data to be transformed.

New implemented nodes are:

- **GoGoSinkSource,** a node to support the go-go [131] interaction technique.
- **ZoomSinkSource**, a node to support remote-controlled zooming of LANC[25] compatible video cameras.
- **PanTiltUnitSinkSource**, a node to interface a pan tilt device from DirectedPerception[26].
- **SysMouseModule**, a node to control the mouse pointer of the operating system.
- **NFTracker**, an interface node enabling the use of natural feature tracking [166]. This solution allows the tracking of maps or textured scale models without the need to place fiducial markers in the cameras view.

Image-based tracking nodes in OT rely on video images from OV. The routing of the video images from OV was reimplemented to simultaneously supply all vision-based trackers in the OT graph, which can now select their preferred video source.

23 http://www.ar-tracking.de/ (02.10.2010)
24 http://www.intersense.com/ (02.10.2010)
25 http://www.avitresearch.co.uk/control-l.htm (02.10.2010)
26 http://www.dperception.com/ (02.10.2010)

3.1.3 OpenVideo

OpenVideo[27] is designed to be extensible and easily configurable, interfacing various video and image sources. The runtime structure of OV is also implemented as a directed acyclic graph which consists of nodes and edges with special support for video data. The graph of OV is build from an XML configuration file. It was extended by the author to simultaneously support multiple DirectX[28] video sources.

3.1.4 Muddleware

The idea of Muddleware [165] is to provide a middle-ware framework for distributed off-line communication of different instances mediated by a central server. Data is stored persistently in an XML database which allows the usage of XPath[29] queries. Data synchronization can be carried out, especially for a multi-user system with multiple clients. It also allows the synchronization of heterogeneous systems (*e.g.* a mobile device with a desktop-based system). In combination with Studierstube, multiple instances of applications can be synchronized via Muddleware in an effective way.

3.2 MR Tent

The idea of the MR Tent [100] is to move out of the laboratory into the field and enable experiments with MR technology right on the site of urban reconstruction. This step is necessary for realizing true AR, so the environment of the real world can be augmented live, in real time, allowing interaction and virtual modification of the MR scene.

The author initially provided technical requirements and was loosely involved in the design process during the development of the first two concepts headed by the Viennese team. For the final design the author engaged to communicate the necessity to respect the technical requirements which limit design significantly and to use them as a basis for progressing the MR Tent design to improve technical feasibility. Assembly and deployment of the prototype was headed by the author.

27 http://studierstube.icg.tu-graz.ac.at/openvideo/ (02.10.2010)

28 http://www.microsoft.com/games/en-US/aboutGFW/pages/directx.aspx (02.10.2010)

29 http://www.w3.org/TR/xpath20/ (02.10.2010)

The experience from 5 participatory workshops in IPCity and several multi-disciplinary discussions went into the development of the MR Tent enclosure, described in the next section. In parallel to the hull design, the interior workspace was developed, serving as a collaborative interface to MR technology probes. *Chapter 5 Workshop Experiments* summarizes the participatory processes which contributed to the interior design and technology layout inside the MR Tent. The final section on the MR Tent outlines the initial assembly and the initial physical deployment of the developed prototype enclosure.

3.2.1 Enclosure Design Stages

The requirements added up to an extremely long list of wishes and sometimes even contradictory needs. The tent design process started exactly with the project kick-off, a presentation suggesting influences and impact of the tent design on the public in the environment where the tent will be deployed. Historic background involving artistic installations as well as hi-tech hull solutions were outlined as a basis for the further development of the MR Tent idea.

The following list is a reduced version of the initial requirements. The list and the rendering suggesting an interior layout in Figure 7 was communicated to the architect Mathis Osterhage, who engaged to further develop the design.

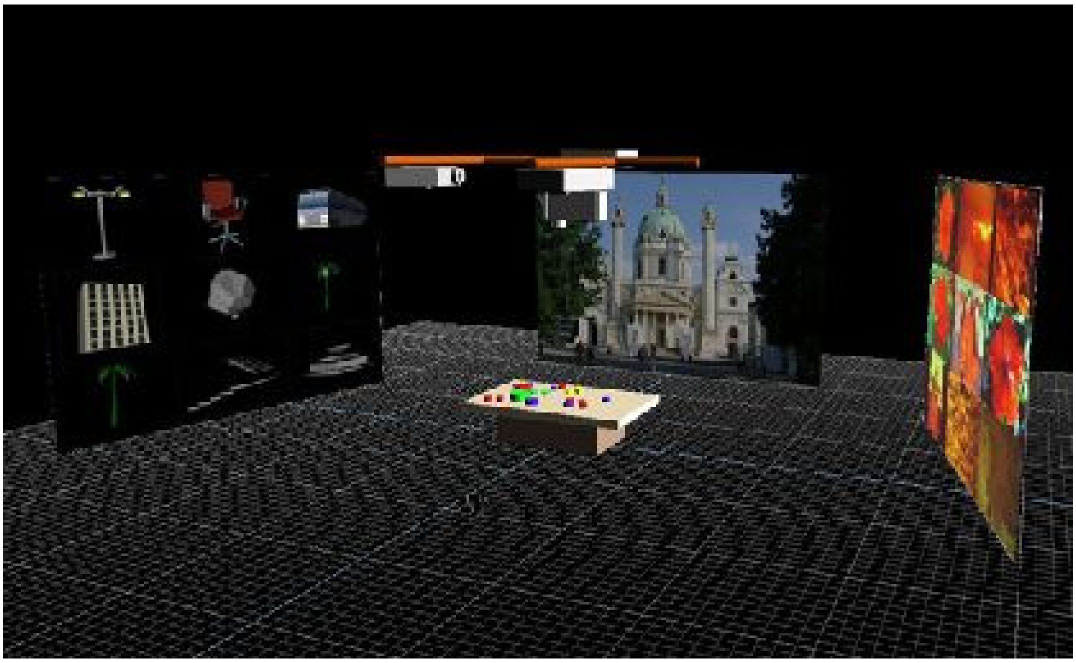

Figure 7: Tent Interior Design Proposal (T. Psik)

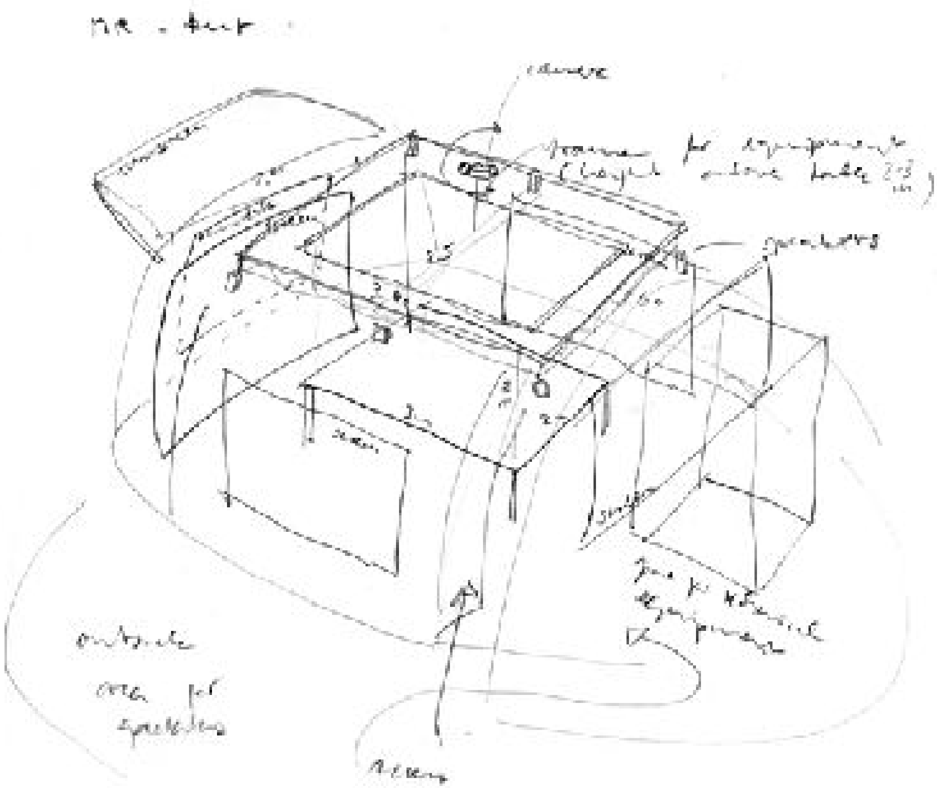

Figure 8: Principle Sketch of the Initial Tent Idea (M. Osterhage)

The key requirements and insights gained from several communications were visualized by the architect in the sketch shown in Figure 8.

Key Tent Requirements:

- “easy to set up”
- “easy to transport”
- weather proof
- at least one surface 3x2.5 m for projection
- at least two surfaces at the sides for projection
- two tables of 1.5x 2m or one 3x2m
- space for 10-15 people to stand around the tables
- construction 2.5 to 3 meters above the table for projectors etc.
- tracking equipment frame 3.60x3.60m
- 6 loudspeakers
- camera on top of the tent
- space for technical equipment
- space for visitors and spectators outside the tent
- at least one part of the tent
  (near the front projection surface)
  should be removable (approx. 1.5x 2 meters)
- sun screen to reduce sunlight

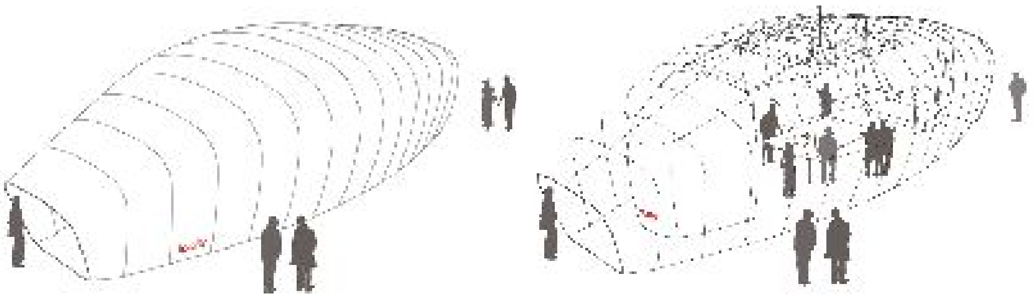

Figure 9: First Design Concept of the MR Tent (M. Osterhage)

With the sketch as a basis, the development process led to the first design proposal as documented in Figure 9 by an initial tent design.

One of the intermediate technology reports of the architect states: "*... in an experiment that had been conducted by the team of the Technical University Vienna with a tent and a variety of projection setups ... , it became evident that a high degree of openness of the enclosure and flexibility of the possible arrangements of walls and screens and a good visual link to the urban context are crucial ...*" Based on this input the second tent design concept shown in Figure 10 was created.

This design has the high degree of openness demanded, flexibility and adaptability. Further requirements were scrutinized stating that the maximum duration in one location of the installed tent is two days and quick and easy installation in a couple of hours by a maximum of four people is important. Packaging and transportation should be efficient, thus a size of 3,3 x 5 m and 3 m height was agreed on. The new table size is 1 x 1,7 m. The rectangular and de-

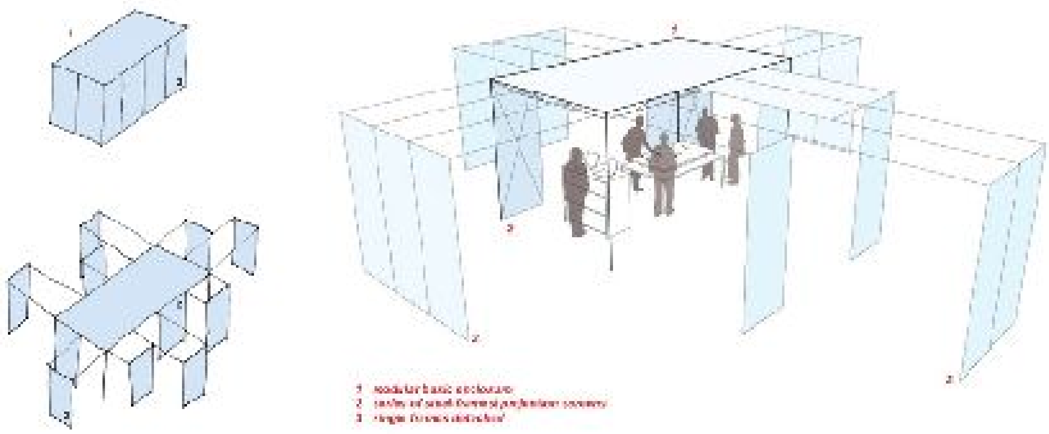

Figure 10: Second Tent Design Concept (M. Osterhage)

tachable side frames of the construction were thought to be filled with semi-transparent projection screens allowing to partly see the environment around the tent. A modular build of the system should allow multiple spacial configurations.

Consent seemed to be near when this solution was discussed among the Viennese development team. The practical aspects of manufacturing and using this tent construction raised new problems when the critical engineering aspects were considered. Firstly, there was a very high cost estimate for manufacturing the prototype. Secondly, using an open hull approach raises the problem that handling an extremely high dynamic range of light intensities imposed by the sun and weather is not possible with available projector technology.

A new design was needed respecting all the engineering considerations raised by the author, based on technical limitations of available MR technology. Two key engineering issues were identified to be essential for creating an MR environment inside the tent, both concerning the lighting situation of the environment under all possible weather conditions (*e.g.* dark at night, windy, rainy, cloudy, bright sunlight, spring, summer, fall):

- Screen projection luminance allowing visibility in all weather conditions is limited by the 5500 ANSI lumens of the projector.
- Stable light situation on the central table allowing computer vision based tracking is limited by light invariance of the algorithms under development.

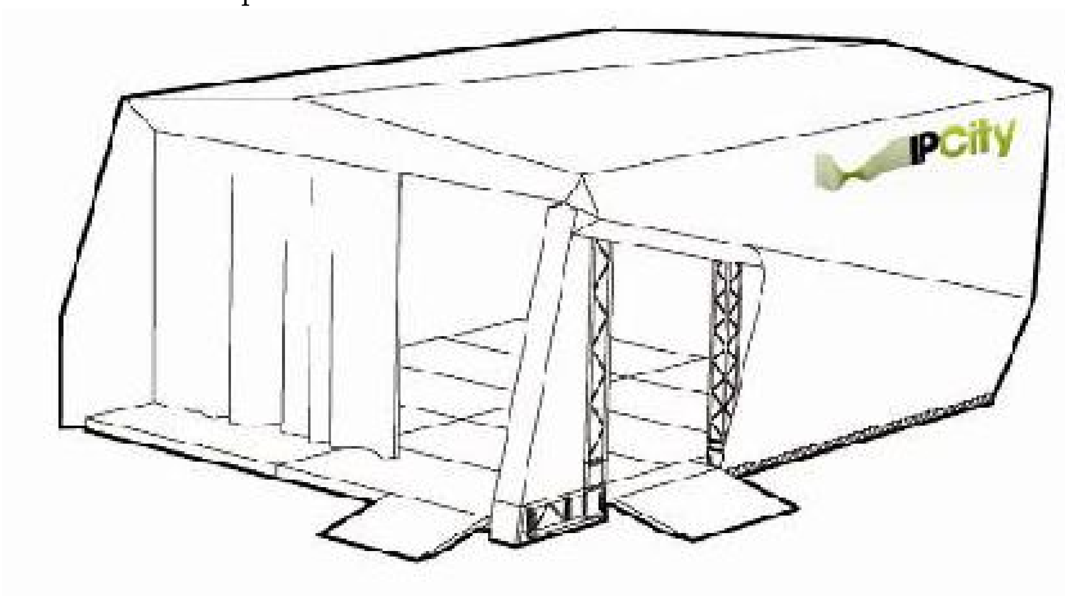

Figure 11: Third Tent Design Concept (J. Illera)

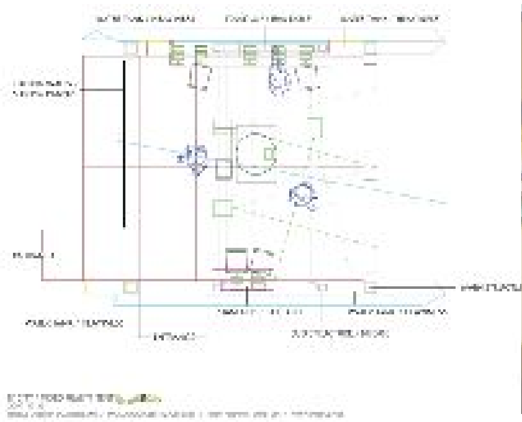

Figure 12: Third Tent Plan and Model (J. Illera)

Based on the design history and constraining technical requirements the third tent design was created by Jakob Illera, who presented a redesign of the tent idea. The compromise for the enclosure design is illustrated in Figure 11. Plans, a miniature model and material samples were presented in a subsequent meeting (see Figure 12).

The new design solution with an inner and outer hull allows to block the sun-light to a reasonable extent, as one side of the tent can be opened to control the amount of light entering the experimentation and working area in the tent. An additional window opening on the other side of the tent is partly screened by the outer hull, so direct sun radiation can be avoided to some extent. The window and its configurable material serves for experiments regarding the perception of visual inside and outside environment cues. At this development stage furniture was considered to be kept to a minimum and designed for organizing people's movement and handling of the technical equipment and interfaces, thus regulating the physical interaction space. The size of the tent limits the number of people that can enter the interaction space and the diameter of the central round table limits the number of people who have simultaneous access to the tangible interface. Interior design also affects the sketching interface. Details on the development process of the collaborative interaction space are part of *Chapter 5 Workshop Experiments*.

Although there are downsides regarding transport and assembly involving weight and volume of the parts, this presented tent design concept led to the joint decision of the involved researchers to build and setup the tent including the MR technology probes, thus physically creating the MR Tent as a mobile research facility to enable the exploration of the mixing of urban realities on site, technically required to enable AR.

3.2.2 Prototype Assembly and Deployment

Figure 13: MR Tent Parts and Construction

Although the MR equipment is protected by the tent, weather conditions are to be considered carefully when planning workshops and events, because the participants comfort is affected and setting up the tent in rainy weather is arduous. In the initial structure, canvas and interior design of the MR Tent provide a useful base for experimenting with a mobile mixed reality environment. Transportation and setting up the tent is challenging, especially given the amount of weight that is needed in order to provide stability in heavy winds. Figure 13 shows the packaging of the parts on the left. It documents a stage during the initial assembly by the author and many valuable helpers on the right.

Figure 14: MR Tent Construction and First Assembly

Figure 14 gives more insight to the construction process and depicts the initial setup of the tent enclosure. Figure 15 shows the result of the MR Tent prototype setup on the campus of the Technical University of Graz. The Enclosure was constructed and a trial with the MR technology probes in the interior space initiated the mixing urban realities research with the explicitly designed MR Tent, now contributing to the overall development of urban communication processes. See the next section on the results of the specific MR technology components used to create the workspace environment.

Figure 15: First Assembled MR Tent Prototype

3.3 MR Technology

The MR Tent combines multiple MR interfaces, thereby bringing collaborative MR from the laboratory to the field. The whole MR Tent environment is designed to support urban collaboration and communication processes with MR technology on site in reconstruction places. Technology requirements evolved and were scrutinized as probes [68] deployed in workshop experiments.

Figure 16 gives an overview summarizing the results of numerous interface development cycles. In the following a brief description of the illustrated components is given, which are then described in detail in the subsequent sections. In the center of the MR Tent stands a round table with a map serving as physical orientation and giving multiple users simultaneous access to the MR scene. A wall projection gives feedback of the MR scene and is controlled by laser pointer input. Next to the entrance, a small overview map of the site is tracked, providing the interface for adjusting the bird's-eye view. Outside the tent, a human MR scout [137] equipped with mobile AR is directed to contribute external views. All interfaces are integrated by the Urban Sketcher [151] application, so egocentric as well as exocentric perspectives are equally visible to all collaborators (unlike 3D stereoscopic visualizations, which mostly give individual perspectives) in the MR Tent. The interior layout was developed in collaboration with project colleagues. The development of the central table with the tangible interface and the left side of the tent was headed by the Viennese team. The right side of the tent interface including sketching, scouting, live augmentation and map tracker was coordinated by the author.

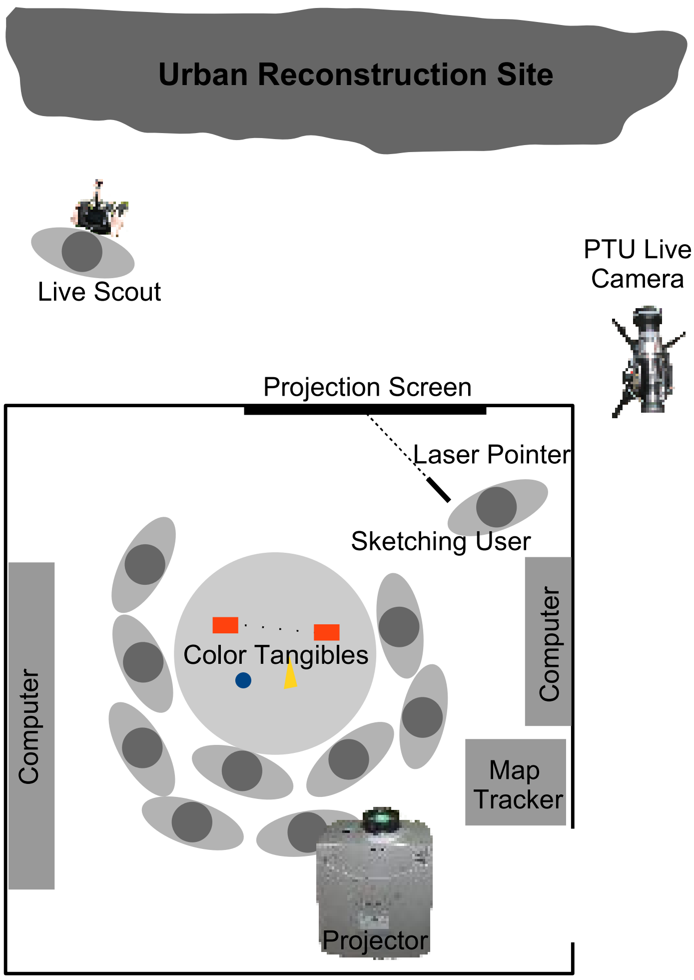

Figure 16: MR Tent Interior Interface Layout

This experimental interface configuration was tried out during two different scenarios in workshops which provided different settings concerning urban and environmental aspects as well as different groups of participants. Furthermore, it was introduced to the broad public at exhibitions. Details are summarized in *Chapter5 Workshop Experiments.*

The user-centered participatory design of MR Technology development was strongly influenced by workflow considerations common in urban renewal processes. The three major communication needs identified were addressed by project colleagues and the author with the developed MR tools:

- The moderation of the communication processes is supported by the central projection focusing the attention and the screen-based laser pointer interface for directly interacting with the shared MR scene. Furthermore, 5 different *viewing modes* (explained in section *4.2.1 MR Views of the Environment*) are available for reconstructing the urban site:
  - Panorama View
  - Tangible View
  - Bird's-Eye View
  - Pan-Tilt Camera Unit View
  - Scout View

  The laser pointer allows the user to focus attention on any real or virtual object in the tent that makes the device a versatile moderation tool.
- The need for individual support when expressing a point of view is also addressed by the screen-based interface. Especially the 2D overlay menu gives access to many tools for sketching in the MR scene as well as for inserting and creating content. The laser-pointer operated tools for expressing the individual vision are available for all 5 different viewing modes.
- The need for multiple simultaneous information access and possible interaction with the MR content was realized by including color tangibles used on a map or plan of the reconstruction site. The overall interface integration allows simultaneous user input from various connected devices and can be extended for other devices and applications using the user interface API of Urban Sketcher.

The dynamic character of the communication process in the MR Tent cannot be automated easily, as numerous dynamic influential factors are involved. Essential needs can be identified and lead to interface optimizations in a participatory process. In addition, constraints are imposed by the reconstruction scenario itself.

Individual work with content and some special interface configurations are required for optimal support of significant stages in the dynamically changing workflow.

The MR technology in the MR Tent is based on the integration of several components. The following section gives an overview of the ColorTable and its components. In the consecutive section, projector and screen used for output are described, followed by a description of the input devices, stylus and laser pointer. The section on pan-tilt camera unit explains how those devices are connected to software components. The scout section explains functionality and limits concerning the scouting development. Finally the section on Urban Sketcher leads to the next chapter where the application and integration solutions are described in detail.

3.3.1 ColorTable

The entire color table [96] was developed by the Viennese team, with advice from the author concerning infrastructure and performance improvements. It is called ColorTable due to the colored tangible objects on the table. With Color-Table, not only the physical central table (Figure 17) is meant, but a conglomeration of software components working together to form a tangible VR application, which was originally designed by Dr. Thomas Psik and is thoroughly described in the thesis of Maquil [97]. The following schema (Figure 19) intends to provide a rough overview of the technology

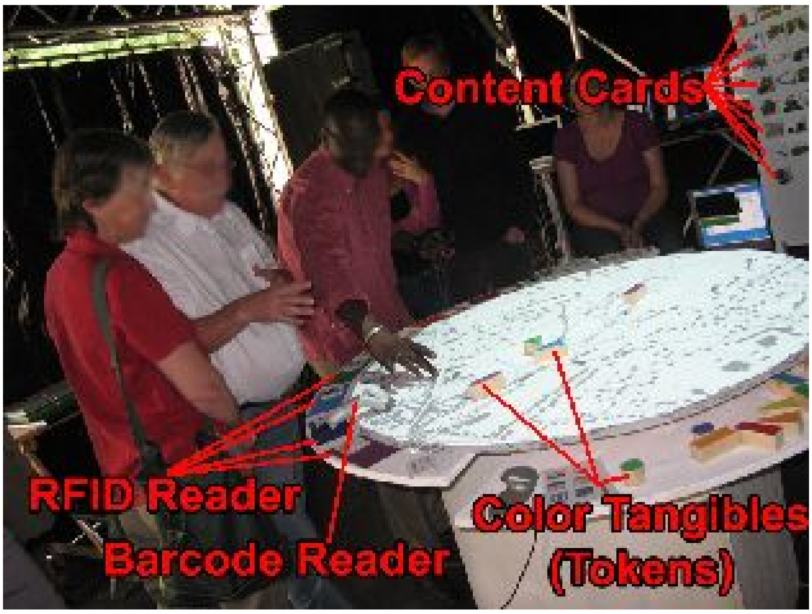

Figure 17: Color Table Interface

components and the information flow between them. This is useful for understanding the software integration solutions developed by the author. Figure 17 shows some users around the physical color table, with communication supported by a map of the environment. The table interface is operated by placing content cards on one of the color coded RFID[30] readers. The content is assigned to the tokens with the corresponding color and is inserted as an object into the MR scene.

In Figure 18 a user moves a token on the table, this influences the position of the assigned content in the MR scene, which is projected to provide a perspective view of the manipulated environment. Further functions of the Color Table are creating roads and marking areas, indicating different uses as well as saving and restoring the history of the created MR scenes using a barcode[31] reader for command input. A small camera is used to digitize sketches on paper. In a second step, the sketches can be placed in the MR scene using a token.

Figure 18: Color Table and MR Scene Projection

On the left side of Figure 19 hardware inputs are visualized. The color tangibles tracking generates the physical location of the tokens (colored round, triangular or rectangular tangible objects) on the table with computer vision algorithms. The top table projection component computes the visual feedback projected onto the tabletop and forwards the token positions to OT. Table rotation, barcode reader, RFID reader and camera inputs are processed by their respective interpreters, which are all connected to the Muddleware

30 http://rfid.org/ (04.10.2010)

31 http://www.barcode-1.com/ (04.10.2010)

DB for changing the applications state. Content is downloaded from the HMDB to the file system and inserted into the MR scene based on an ID provided, *e.g.,* from the RFID reader. The perspective output is computed by a Studierstube application called eDesigner based on information from the Muddleware DB and OT.

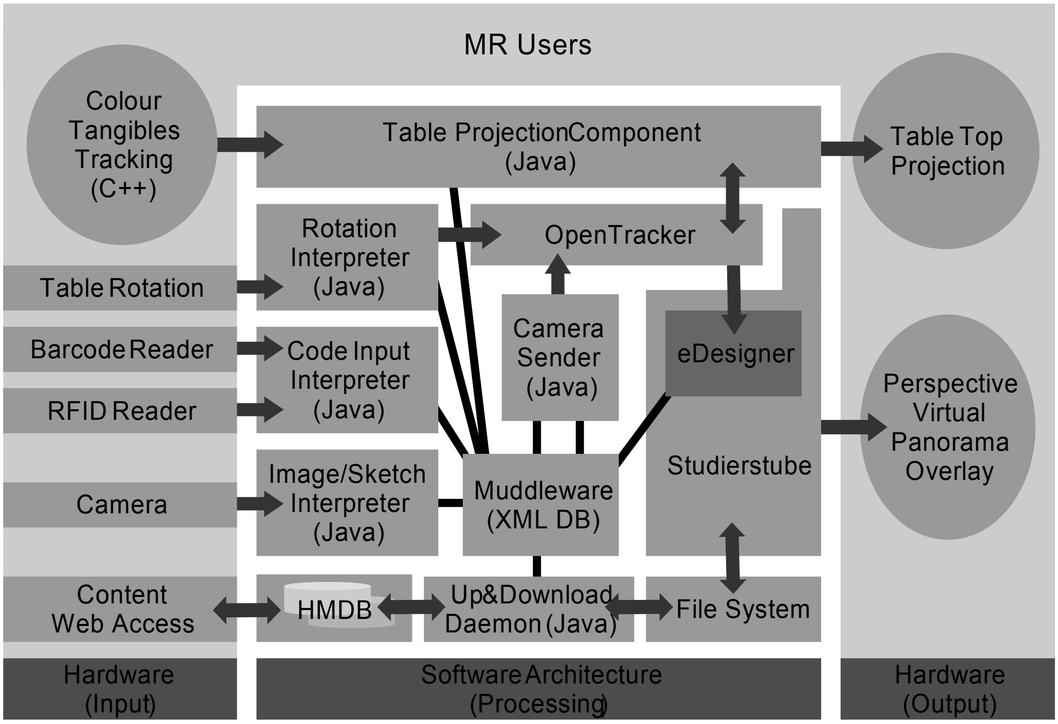

Figure 19: Color Table Schema

The development work done by the author was the conversion of the eDesigner application into a component of Studierstube. This solution enables the integration of all Open Inventor nodes developed for the Color Table into another application like Urban Sketcher. For more details on the application integration, see *4.2.4 Application Integration.*

3.3.2 Projector and Screen

As already mentioned in the section *3.2.1 Enclosure Design Stages,* the lighting situation of the environment needs to be controlled, so enough visibility of the projection remains in a mobile outdoor installation. The projector used in the MR Tent is a Sanyo PLC-XP57L projector with 5500ANSI lumens, a wide angular lens LNS-W32, motorized zoom, 1000:1 contrast ratio and suitable for running 24h/7days. The integrated perspective correction can be used for adjustments when projecting with large angular offsets, which was not needed in the MR Tent, but in laboratory setups at universities. In a demonstration prior to the acquisition of the projector capabilities were tested and compared to other models available in a showroom by Dr. Reitinger and the author, who both stressed daylight capability and high contrast.

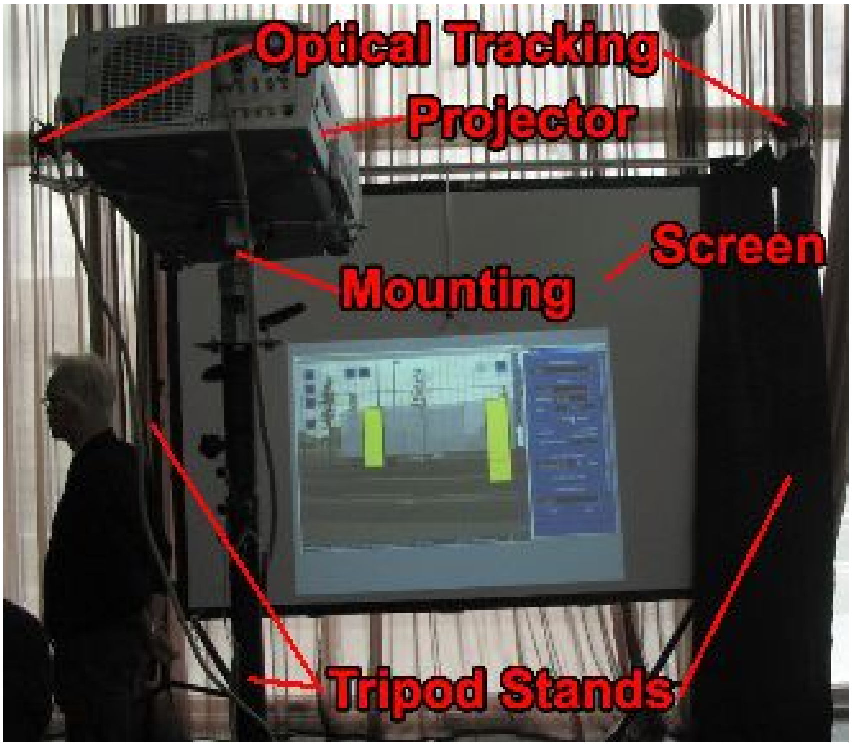

Figure 20: Projector and Screen Mounting

In order to be flexible and support a range of setup configurations, the mounting in Figure 20 was created with standard parts. An initial solution for mounting the screen and for rigidly attaching optical infrared tracking on tripod stands as shown was created.

3.3.3 Stylus / Laser Pointer Input

First thoughts on developing a stylus-based interface on a large screen involved the acquisition of a whiteboard with integrated stylus tracking, as there are several commercial solutions available. The use of a 6 DoF optically tracked stylus and screen instead is more cumbersome regarding setup and configuration, but provides more possibilities for experimentation, as the interaction space is not limited to the screen plane. A large screen size was chosen, so a large number of people can have the same view of the MR Scene.

When working with a large screen, a stylus type interface is convenient. The development of a tracked stylus in front of the large screen started with an optically tracked device, which was a standard laser pointer enhanced with special infrared- light reflecting markers, so it could be tracked with a standard A.R.T. System[32]. The button functionality of the device is transmitted wirelessly to a USB connection. The 3D location data of the tracked pen had to be transformed into the screen space of the tracked large display. This is done in a custom-built OT node. This node is further connected to another node of the graph, which maps the 2D movement to the mouse pointer of the operating system (see *3.1.2 OpenTracker*) and controls it as long as the stylus is in tracking range near the screen (Figure 21) and therefore emits events.

Figure 21: Sketching with Optically Tracked Stylus

Findings of early workshop and laboratory experiments testing different interaction distances between the user and the screen showed that it is interesting to enlarge the interaction space, so it is possible to "*point*" from a distance to the screen, which is partly possible with the optical tracking configuration limiting the interaction space to approximatively one meter in front of the screen. The

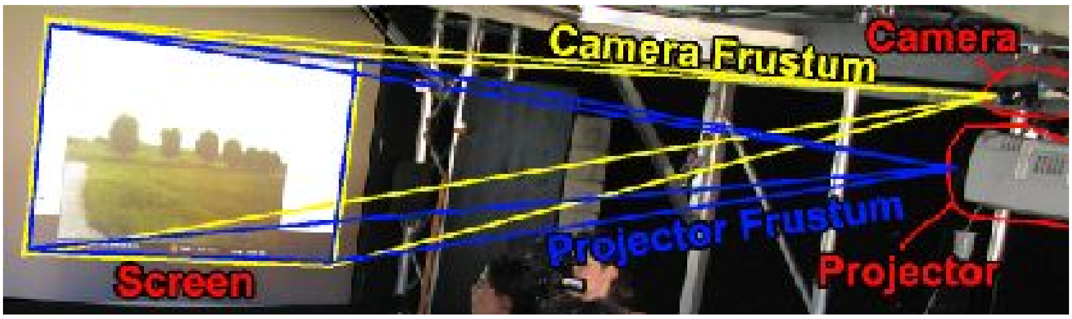

Figure 23: Projector Camera Setup for Vision-Based Tracking

32 http://www.ar-tracking.de/ (04.10.2010)

Figure 22: Sketching with Laser Pointer on Projection Screen

new idea for the interface was to track the dot of the laser pointer on the screen, so the interaction space is only limited by the reach of the laser pointer.

A new node in OT was written to filter the green laser dot from a video stream of the large displayed screen. An initial calibration step calculates the homography between projector and camera frustum (see Figure 23), so a good mapping of the laser dot to the displayed image is possible, see Figure 22. The simple vision-based tracking implementation worked at a reasonable frame rate, not yet absolutely optimal for controlling fast movements of the mouse on the screen, but enough for standard tasks. Just recently camera-free dot tracking became available by the product of isiQiri[33].

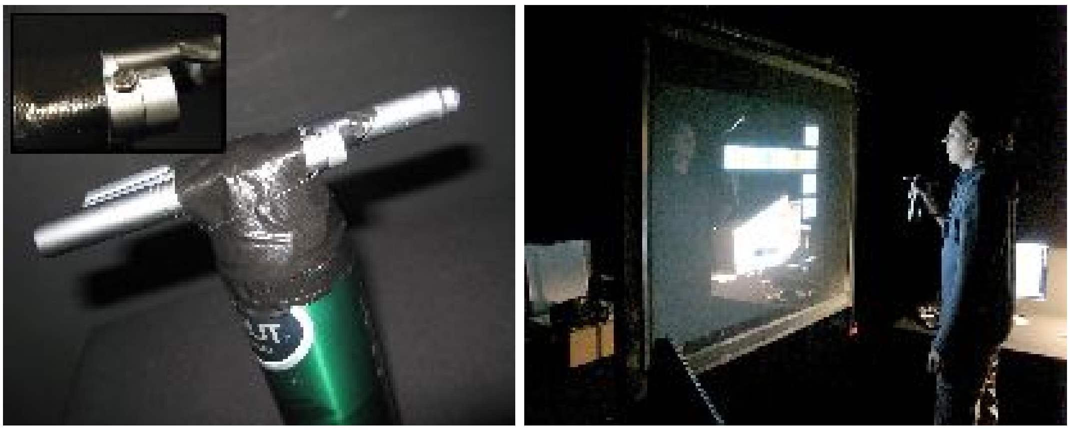

Figure 24: Spray-Can Laser Pointer Interface

33 http://www.isiqiri.com/products/ (04.10.2010)

Figure 25: Final Laser Pointer Stylus Prototype

During a research visit to HITLab NZ, the laser-pointer based spray can device was developed and tested in collaboration with Raphael Grasset (Figure 24). It was found by the developers to be very intuitive and ergonomic to handle due to differences in shape and hand posture.

During a workshop it became clear that the design and functionality of the laser pointer was still insufficient. The button needed improvement for sketching on the screen and the weight of this prototype was to high. The main issue was that the user had to concentrate on putting a lot of pressure on the right place of the button, in order to obtain the desired result of triggering an event. For this reason the Laser Pointer pen design and functionality of the button was further improved. First the weight was reduced by removing two batteries and the casing of the transmitter of the button. The circuit board for the transmission of the button trigger event was taped to the outside of the laser pointer case and the power was connected directly to the supply of the laser pointer. The result did not look nice, but is very ergonomic and weights only 80 grams (Figure 25).

Figure 26: Final Stylus with Attached Optical Targets

The old button was also replaced by a new one, reacting at high precision requiring a minimum of pressure. In summary, the final laser pointer stylus has unconventional appearance but works well, so the user can concentrate on her work and is not distracted by the stylus interface. In Figure 26 the stylus is shown with an adapter integrating optical tracking targets so it can also be used in such a tracking environment for interface experiments.

3.3.4 Pan-Tilt Camera Unit

The device combination is shown in Figure 27, where it is set up next to the MR Tent for streaming live imagery of the environment to the inside of the tent.

Figure 27: Pan-Tilt Camera Unit Setup on Site

A panning and tilting unit is often used with a mounted camera in surveillance scenarios. In combination with a remote control and viewing devices it is possible to observe the environment near the combined device by orienting the camera remotely in the direction of interest. Another useful feature is the remote zooming capability

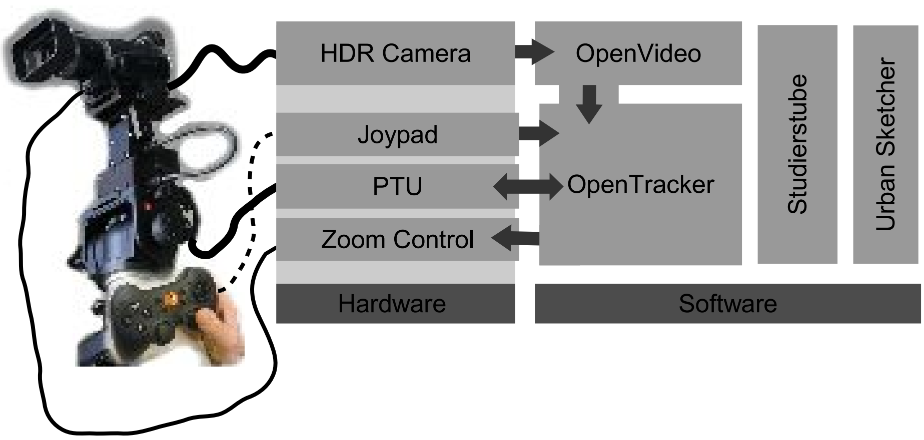

Figure 28: Pan-Tilt Camera Unit Connection Schema

of the camera. Figure 28 shows how the setup is connected to the software components in combination with a wireless Joypad controller.

The camera used was especially selected to support a large dynamic range, thus operating with a CMOS imaging chip instead of a CCD chip which is more limited in its dynamic range. The camera model used is a Sony HDV 1080i.

3.3.5 Scout

The idea of scouting was initiated by Reitinger *et al.* [137]. Initially the scout was used to acquire and transmit single images from the environment to the provisional MR Tent, where they were automatically inserted into the MR scene. After some development iterations and the integration of the Live 555[34] streaming library the scout is finally capable of providing a live geo-indexed video stream from the vicinity of the MR Tent (see Figure 29). "*The network communications are established over WLAN using the latest standard (801.11n), which theoretically is able to transfer data for up to 250 meters in outdoor environments. Nevertheless, the performance degrades with the distance. Tests performed using standard WLAN hardware showed that a stable connection for transferring video data was possible for a range of around 30 to 40 meters.*" [149] Range is limited by the wireless network used. Both WLan and HSPA+ networks

Figure 29: MR Scout Providing an GPS-indexed Video Stream

34 http://www.live555.com (04.10.2010)

were tested. The latter had to be used with a VPN tunnel in order to by-pass protocol and port limitations of the network provider (A1 in Austria). "*… the WLAN connection of the scout was exchanged for a mobile internet connection, removing the position constraints. The current system requires 120Kbyte/s upload bandwidth for a 160x120 image, thus requiring at least 1Mbit/s upload speed. Theoretically, the newest mobile technology supports upload speeds of up to 5.76Mbit/s.*" [149] The video stream includes the spacial location of the scouting device, thus position and orientation. Initially the scout was developed on a UMPC from Sony with a 1GHz processor. Due to low tracking accuracy it was decided to experiment with tracking methods supplementary or alternative to GPS. The use of

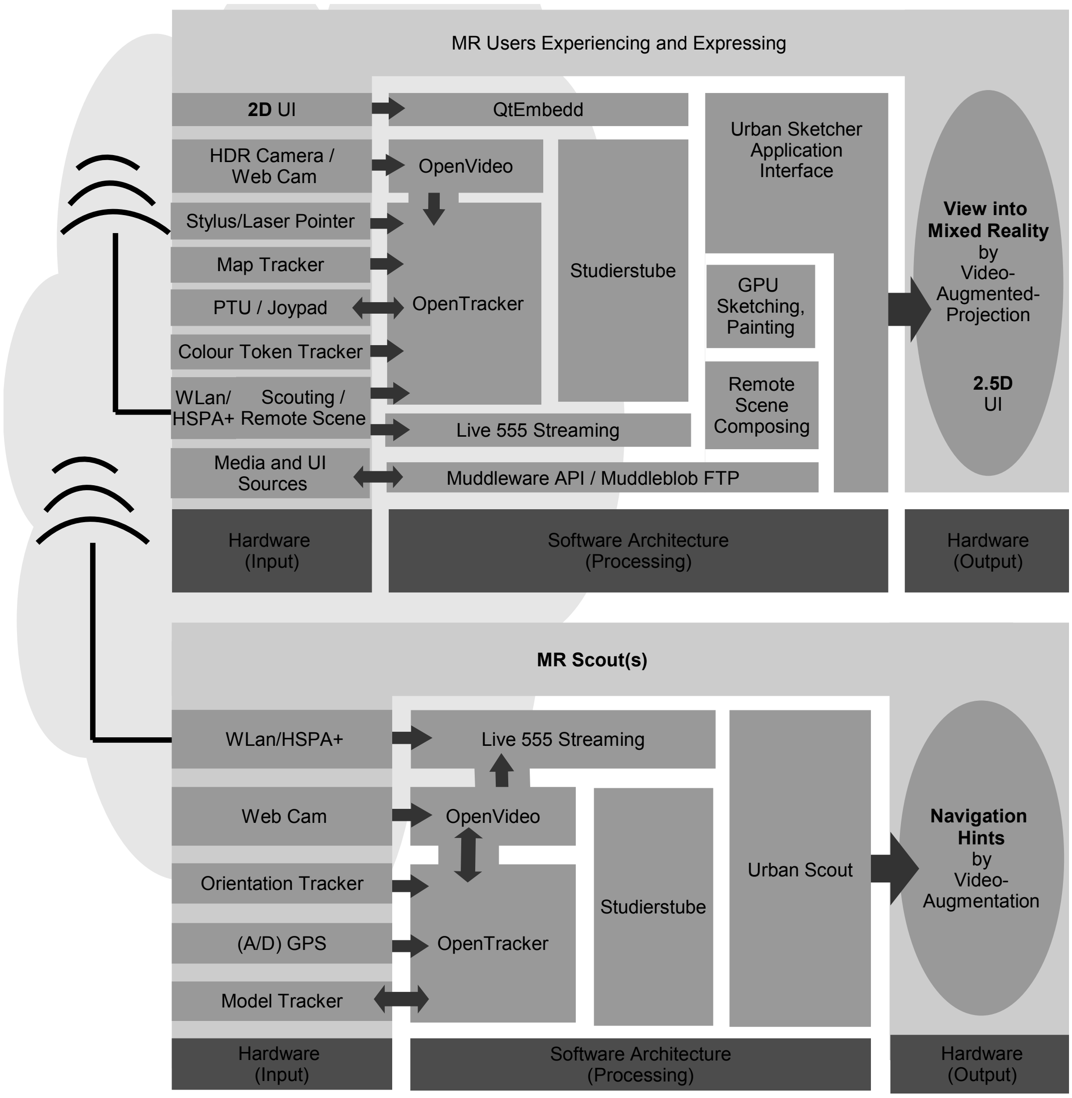

Figure 30: Scouting Components Schema

computer vision-based tracking and real-time video compression is computation intensive, therefore an AMD Turion dual core 2.4ghz Tablet-PC was chosen as new experimentation platform.

Figure 30 shows the components of the scout and the information flow between them in the lower part of the illustration. In the upper part the receiver of the scouts video stream, Urban Sketcher, is outlined and will be described in detail in the next chapter. The environment of the scout is captured by a web cam, this imagery is then distributed by OV and encoded in real time as M-JPEG and sent via the wireless connection. Included in the stream is the current position and orientation of the scout gained by GPS and orientation sensors. Model-based tracking similar to "*Going out*" [139] works with a textured model of the environment and was deployed to replace GPS, but did not provide sufficient results at this early stage of development. Nevertheless, this approach seems promising if a 3D model of the environment is available or can be generated on the fly.

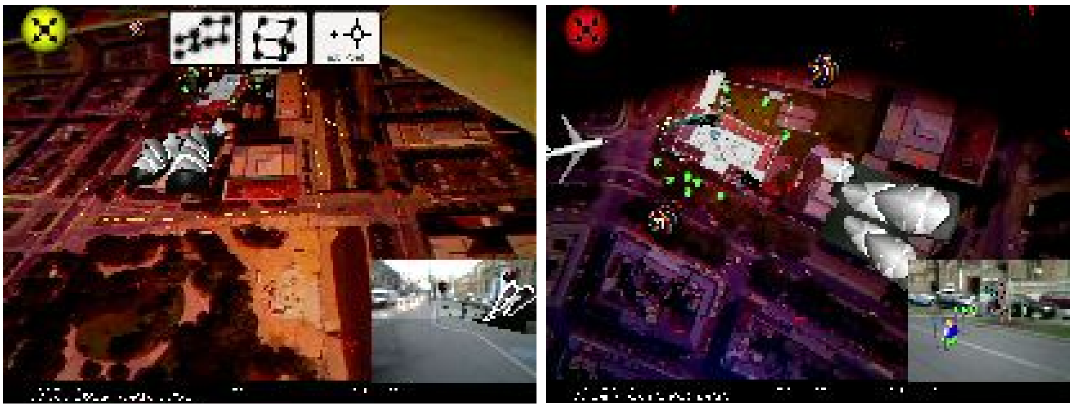

Figure 31: GPS Scout over HSPA+ Live Streaming MR Scene

Figure 31 shows the renderings based on the received data from the scout. The small window on the lower right shows the video-augmented live scouting perspective, whereas the large overview shows the whole MR scene in combination with a map including the path of the scout. The communication between the stream receiver in the MR Tent and the scout is important for navigation especially when larger areas need to be covered and simply shouting towards the scout is not heard anymore. One implemented solution in addition to text chatting is the scout indicator. This is the little blue avatar (see Figure 31 right) which can be moved by the users on the receiver side to guide the scout around the environment. The avatars location is synchronized to the scout's-augmented view and indicates where to go or look.

3.3.6 Urban Sketcher

The section MR technology subsumes developments working with the software infrastructure. They are deployed in the urban environment using the MR Tent to create a workspace for mixing urban realities. In a cycle of continuous user-centered development, evaluation and redesign the experimentation application Urban Sketcher was developed. Urban Sketcher interfaces and unites technology components and other applications thereby integrating MR interface capabilities to form a unified workspace accessible by tools. The application is the subject of the following chapter.

Chapter 4
Urban Sketcher

Urban Sketcher comprises a set of MR tools for viewing, sketching, painting and manipulating the MR scenes, thus enables users to express their visions by "sketching" MR scenes. One prominent interface is operated with laser pointer input on a large display inside the MR Tent, showing the rendered view in the MR scene. Another well accepted and studied interface configuration allows input with a stylus on a 12.1-inch tablet display.

Tracked HMDs restrict free movement and direct eye contact when used for displaying visual user interfaces (UI), thereby imposing constraints on human-human communication processes. In contrast, fixed or handheld MR displays, as used with Urban Sketcher, can present information simultaneously to a group of collaborators, from the same point of view, establishing a common base for eye-to-eye discussions, which are rich in communication cues and social affordance needed for mixing urban realities (*2.2.2Collaboration and Participation*).

Early versions of Urban Sketcher build upon Grasset's work [52]. Urban Sketcher is the result of an iterative process of design-evaluation-feedback-redesign within a period of about four years embedded in a series of participatory user-centered urban planning workshops (see *Chapter 5 Workshop Experiments*). The resulting development and design stage of Urban Sketcher is presented in this chapter.

Initial ideas were inspired from experiences made by Al-Kodmany: "*The artist helped to unveil critical issues, constraints and opportunities. The drawings, together with the artists' notes, provided a storyboard of the community's conversation. While the sketches were abstract and inherently less realistic and precise than photographs or computer images, they served an important purpose. These two tools were most helpful in the first stages of the planning and design process.*" [3]

The intention of Urban Sketcher is to enable work with photographs and models as well as provide tools to generate geometries and support "sketching" in order to enhance urban communication processes. Key issues concerning media content selection and generation as well as interface design are addressed by Urban Sketcher. Furthermore it supports pedagogic assistance, moderation and direct interaction with the developed MR tools.

Concerning the multimodal representation of the MR experience, it is important to note that unlike many VR applications, perfection, *e.g.,* photo realism is not necessarily a goal of Urban Sketcher. On the one hand, the fidelity of the real world cannot easily be matched for all modalities, and sometimes it is enough to just add some simple information augmentations to communicate relevant information. Handheld devices have the potential to provide a strong mobile interface, whereas stationary technologies have their strength in face-to-face or even better in eye-to-eye collaboration. Complex tasks can afford a fusion of real and virtual worlds that is indistinguishable for human perception even involving all senses. The combination of various types of in- and output devices by interfacing their infrastructures closes the gap between different levels of scale or merges individual strengths and thereby enriches the possibilities for the overall communication process as a social service.

The research questions stated in the introduction guide the development and design process of MR hardware and software components as well as the resulting interfaces which enable collaborative work in the MR environment.

The following section gives an overview of the system involving users, environment, hardware and software. Dominant components of the system are described in the consecutive section, regarding MR views of the environment, GPU sketching and painting, application integration, spatial projective augmentation, and simulation and development. In the subsequent section, the visual user interface is described for both on-screen menu and expert functionalities.

4.1 System Overview

All components have been developed and designed to fit into the MR-Framework Studierstube used for general application development. Studierstube (see *3.1.1 Studierstube*) is a construct itself and is mainly an extension of the retained-mode scene graph Coin 3D[35]. Figure 32 shows prominent integrated components of the highly configurable Urban Sketcher application interface, which is designed to unite interaction and infrastructure components, resulting in MR tools for working with a flexible and open MR information space (MR scene) to enhance communication processes of engaged users.

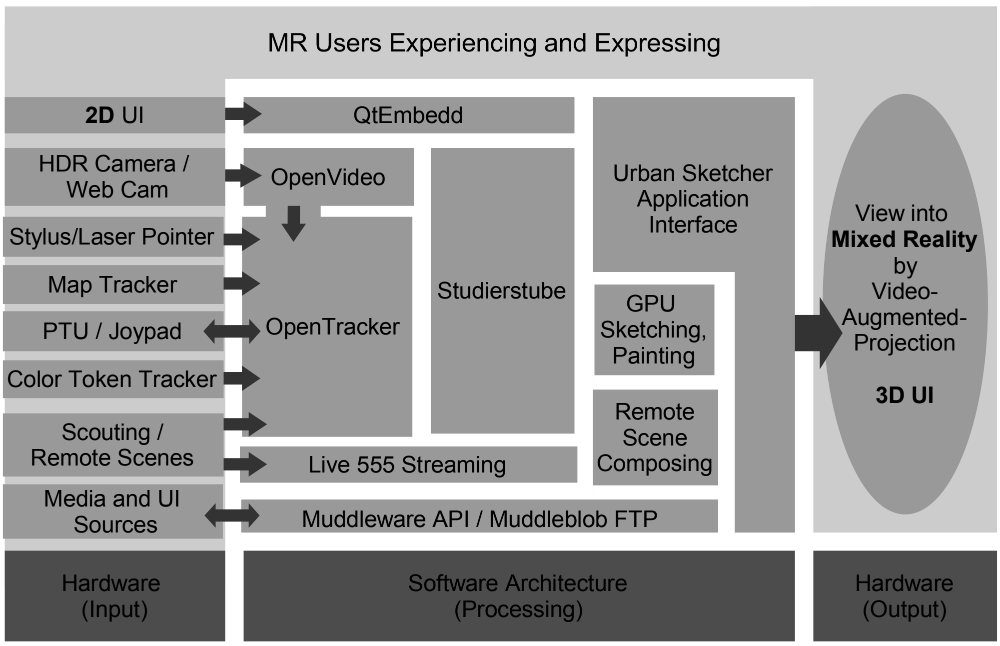

Figure 32: Hard- and Software Integration of Urban Sketcher

35 http://www.coin3d.org/ (04.10.2010)

In the center of Figure 32, prominent software components are visualized to illustrate their interdependencies. On the right the output hardware is represented by an ellipse on top of the light gray area which stands for the MR users, who are also present on the left side, where the hardware input devices are depicted. The flow of information is visualized by the arrows. Important and individual newly developed components are described in more detail in the following section.

4.2 Components

Components are integrated by Urban Sketcher contributing functionality for interfaces and tools.

4.2.1 MR Views of the Environment

Views of the MR environment can vary to a great extent depending on which method is used for combining the MR scene with the real world or a virtual representation of reality, as the MR continuum comprises many forms (see *1.2 Mixed Reality Used for Mixing Realities*). Urban Sketcher supports different variations of views for two major reasons:

- To provide a maximum of flexibility for choosing viewing perspectives, *e.g.,* dynamic egocentric and dynamic exocentric views .
- To provide different levels of realism along the MR continuum for developing and representing content and visions of the urban environment.

A pure virtual rendering and representation of the urban environment is realized with the *4.2.1.1 Panorama View*, *4.2.1.2 Tangible View* and *4.2.1.3 Bird's Eye View*. An augmented reality view combining the real world with the virtual scene requires real-time performance as well as camera tracking and calibration, to make the view port interactive, and this is realized by the *4.2.1.4 Pan-Tilt Camera Unit View* and the *4.2.1.5 Scout View*. The user interface enables the user to switch between viewing modes at runtime. Features of the various view types are described in detail in the following subsections.

4.2.1.1 Panorama View

Possible viewpoints in the MR scene are predefined locations, which can be selected at runtime. Artistically created panoramas surround these locations. These panoramas have depth information included, so occlusions are handled and provide depth cues for the users when placing media content. This viewing mode provides a purely virtual environment (see Figure 33) with navigation constrained to 1 DoF, which allows users to change the viewing direction.

Figure 33: Panorama Views with Occluded Content

4.2.1.2 Tangible View

The tangible viewing mode is in the perspective of a virtual pedestrian observing the MR scene at ground level. In this mode, no background texture is available, thus the background is rendered in black.

Figure 34: Tangible View (view direction see red arrow)

The navigation in the MR scene is interactive, as the view port is attached to the head of an avatar (see Figure 34, blue avatar), which can be freely moved and oriented by the user. The movement is only constrained to the ground plane, resulting in 5 DoF. Figure 34 gives a top down exocentric viewing perspective of the miniature MR scene. The small window in the lower right corner shows the tangible view, which is rendered in the perspective of the avatar.

4.2.1.3 Bird's Eye View

The Bird's Eye View allows the user to adjust the downwards oriented viewing direction into the MR scene by manually adjusting a camera (Figure 35 left) pointing to the desired area of interest on the map.

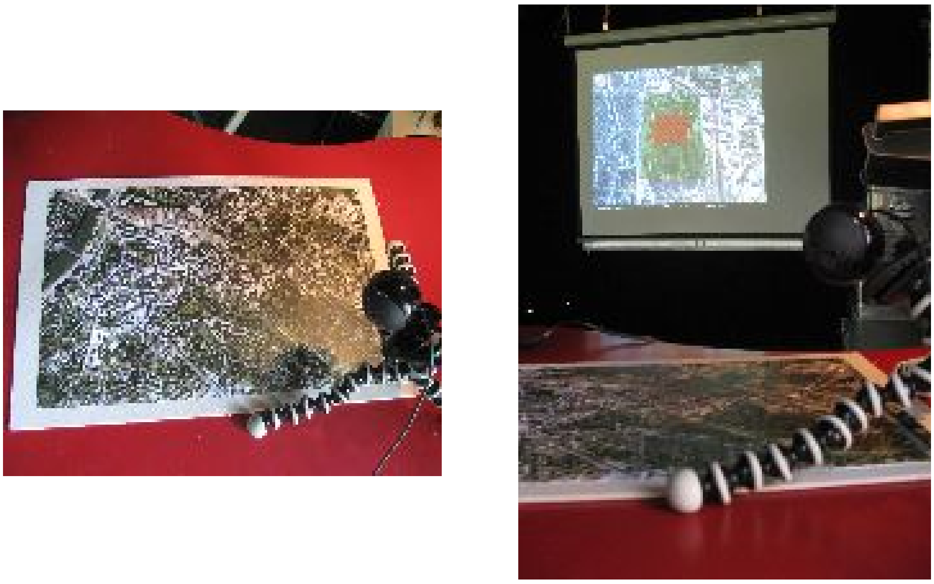

Figure 35: Bird View - Map Interface (left) Rendering (right)

The image stream captured from the map is augmented with the MR scene (see Figure 35 right) and projected onto the screen, so an interactive view from a bird's eye perspective is achieved. The natural feature tracking [166] of a map allows the application to track the 6 DoF of the spatial relation between camera and map without any markers at interactive frame rates.

4.2.1.4 Pan-Tilt Camera Unit View

Utilizing the setup described in *3.3.4 Pan-Tilt Camera Unit*, this view originates at a static position and streams a live view of the real environment (see Figure 36 left), the tripod with the devices is located on the side of the MR tent. Figure 36 2nd right shows the setup in a closeup and Figure 36 (on the right) the AR screen inside the MR Tent.

Figure 36: Pan-Tilt Unit Camera and AR Sketching

The viewing direction and the zoom can be altered interactively with a wireless joypad (Figure 29), while the augmented environment is visible Figure 37.

Figure 37: Augmented PTU view

Technically, the virtual camera is configured and the lens is calibrated to match the camera parameters of the physical camera. The identically matching cameras are needed to render the augmented view representing the digitally synchronized space of the real-world video stream. Real-time navigation is achieved by dynamically updating orientation and viewing frustum parameters.

4.2.1.5 Scout View

The Scout is described in *3.3.5 Scout*. This fully dynamic view (6 DoF) introduces a directable, personal live view of the environment augmented with the scene (Figure 38).

The live video stream of the scout is received including location data. The integration of this video stream and location data is used to augment and render the MR scene in Urban Sketcher from the

Figure 38: Scout in the Vicinity of the MR Tent

perspective of the scout dynamically moving in the environment. The capability of roaming the real environment is considered necessary to obtain different and dynamic points of view in augmented reality. A system for streaming live video and positioning information from scouts that are sent to physically explore the environment with a handheld device was integrated into the MR Framework as a component. This component has the ability of streaming both video and information about the spatial position and orientation of the scouts. Using GPS and inertial sensors for position and orientation information leads to registration errors because of sensor inaccuracies. This further leads to registration errors between the virtual content and the real world. To enhance the tracking, experiments with various sensor combinations including computer vision tracking approaches will need to be conducted in future work.

4.2.2 Phantoms, Occlusions and Layers

Phantoms are invisible virtual objects, which represent real objects. They are needed so occlusions are handled correctly. It was found when working with MR scenes in the urban planning context, it is often sufficient to represent distant real objects with a rough approximations using layers shaped to represent the silhouette of the real objects, due to the more or less static viewing position. This inspired the idea of painting phantom canvases in order to lend depth to real-world objects in outdoor augmentations.

Figure 39 visualizes the idea of placing a canvas at an estimated depth in the scene and using the painting feature to indicate the silhouette of an occluding object. Once a canvas is created to represent the silhouette, in Urban Sketcher, it can be assigned to be a phantom object by pressing the toggle button. Phantom objects are only rendered to the depth buffer. The real-world environment can roughly be modeled like this, so occlusions between real and virtual objects are handled [150]. For editing a button switches into an editing mode, which visualizes all phantom objects and allows the user to edit them.

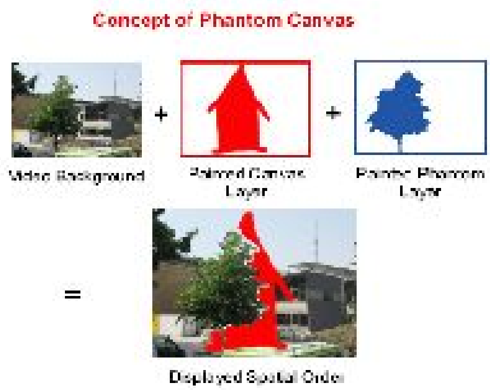

Figure 39: Painted Phantom Canvas layers

4.2.3 GPU Sketching and Painting

The GPU[36]-based texture painting and sketching component was implemented to significantly improve the performance for applying paint onto a textured 3D object in the MR scene. Initial painting solutions were derived from the mediating reality work of Grasset [52]. The ability to work in uninterrupted fashion is determined by the speed and precision at which the visual feedback is given. In order to be able to paint and sketch with reasonable precision, at sufficient frame rates also with small pencil or brush sizes, an algorithm was needed which accounts for texture updates in between frames, more sufficient than just linearly interpolating paint positions between frames. First of all a caching mechanism for mouse events was built, so all available position information can be used to compute the stroke of the brush or pen on the texture in between the rendering of two consecutive frames of the scene graph traversal. After a series of tests, it was found that for very thin lines near to the size of one texel, the frequency of the available mouse

36 http://gpgpu.org/ (04.10.2010)

Figure 40: GPU Accelerated Sketching in 3D Space

events was not high enough to get a closed line when using rather high texture resolutions, so a simple interpolation solution accounting for this issue was implemented. The implemented solution allows freely configuring the painting texture resolution, which is only limited by the graphics hardware responsible also for the final processing speed. Fluent work can be done at texture resolutions up to 1024 pixels (see Figure 40) at any brush size with current GPU power (Nvidia GeForce GTX 260).

In order to support big scenes with more objects than there are GPU texture units available, the implementation loads the painted texture into the graphics memory space when paint is applied to it and writes it back to the main memory space when the current frame is done. To be able to distinguish between textures each texel has an ID corresponding to the object it belongs to. The ID is assigned when the object is created in the scene graph. In this way the picked object is identified and processed in the scene graphs rendering traversal.

Within each frame, the brush size is computed in texels and the needed iterations between two consecutive mouse events as well as the needed iterations to process all mouse events are calculated. With this information the minimum number of cycles needed and all painting positions in texture space are used in an internal rendering loop, where all cycles are executed while rendering the object texture with a screen-aligned orthogonal quad to a frame buffer object[37] with a fragment shader.

With this approach precision is only limited by the mouse event rate and texture resolution, which is in turn limited by the graphics card memory size employed.

The implementation for determining the actual painting object and position in three-dimensional space required to place an ID into the rendered texture of the objects. This implementation can be used to "pick objects" in the MR scene and is useful for activating painting objects by receiving a pointer to it. The result of sketching three green trees using a thin line on an object in a three-dimensional MR scene is depicted in Figure 40.

4.2.4 Application Integration

Urban Sketcher is designed to integrate and unite a variety of MR components. The application utilizes the MR Framework resulting in an open MR information space available to enhance communication processes of engaged users. Two main integration approaches were the basis for integration experiments aimed at uniting Urban Sketcher and ColorTable.

The first approach targeted at tight integration, converting the ColorTable rendering application into a component without neglecting any functionality as described in the following section on the *4.2.4.1 ColorTable Nodes Component* eDesigner. With this approach it is possible to run Urban Sketcher and support all functionalities of the ColorTable and provide a basis for further tightening integration by painting and sketching on tangible objects (see section on *4.2.4.2 Tangibles*) or combining other features of the two applications.

The second solution based on two rendering instances, is a loose integration approach, where one rendered MR scene is sent via the network to another rendering instance, which renders another MR scene in a synchronized coordinate system from the same perspective. With the *4.2.4.3 Remote Scene Composing,* both renderings can be composited into one rendering with the advantage of more com-

37 http://www.songho.ca/opengl/gl_fbo.html (04.10.2010)

putation power and rendering speed independence, due to the distributed rendering. The down-side of this solution is that no tight integration is possible.

A third alternative would have been to work with Distributed Open Inventor [61], but was not realized due to time limitations and assumed implementation overhead. *4.2.4.4 User Interface API* of Urban Sketcher gives access to all important functions of the application and is described in the respective section.

4.2.4.1 ColorTable Nodes Component

The eDesigner component of the *3.3.1 ColorTable* was created out of the former perspective rendering application comprising all major nodes. This software design decision makes the set of versatile nodes needed by the ColorTable available for all Studierstube applications, thus building a basis for tight software integration.

In Figure 41 the interconnections between the ColorTable components and OpenTracker as well as Muddleware are outlined. A rough schema of the instantiated scene graph visualizes relations between the components. The head node, MR Scene, represents the root

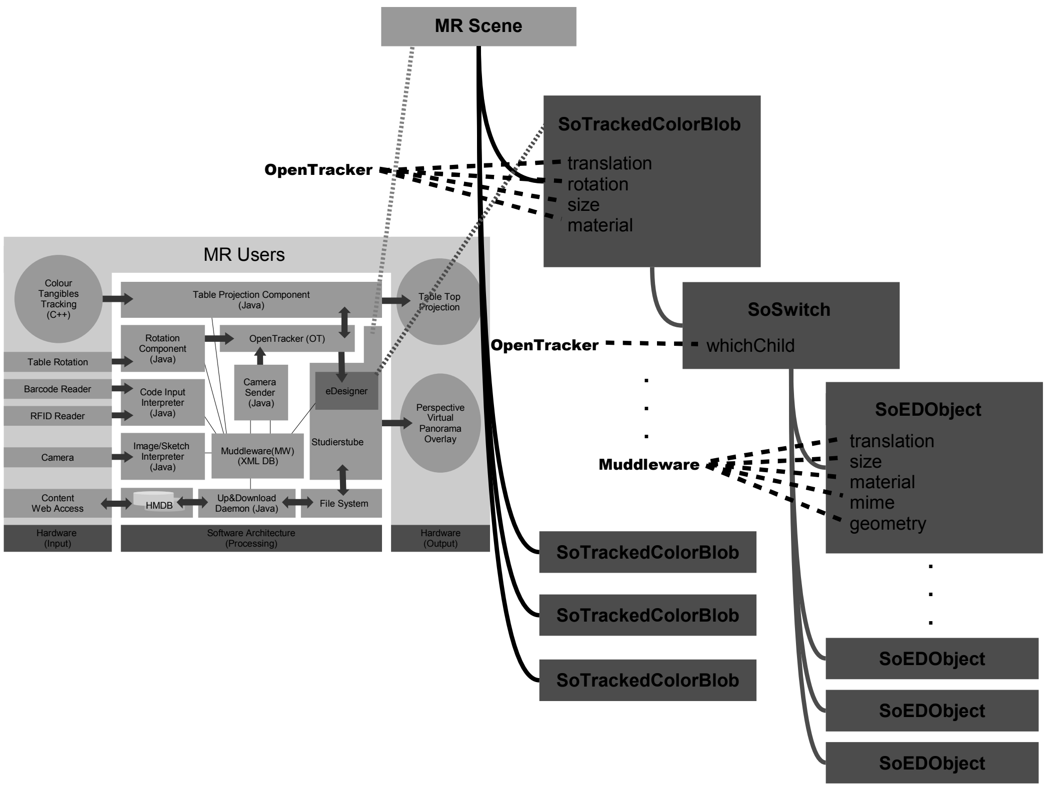

Figure 41: ColorTable Main Node Structure
(see section 3.3.1 ColorTable for Big ColorTable Schema)

node of the scene which holds all the SoTrackedColorBlob nodes, each of which connect to a series of SoEDObject (Figure 41) nodes via a SoSwitch node. In general this design is not memory efficient and the construction is done using a static scripting file. This could be improved by introducing instantiations created at runtime and possibly dynamically created node and field connections would improve memory efficiency, as unnecessary nodes would simply not be created. This was not implemented, as this priority was low for the responsible Viennese team.

First tests with Urban Sketcher using the eDesigner component showed significant performance losses resulting in intermittent non-interactive frame rates below 1 frame per second (fps). This is not acceptable, as sketching is not possible with such a slow rendering. Nevertheless, further experiments and implementations of the author concentrated on the color tracking component of the ColorTable outlined in the next section *4.2.4.2 Tangibles*, in order to progress on real-time capable integration solutions. As solving the encountered speed issues was not considered a high priority by the ColorTable developers, a new integration approach was designed allowing the merging of slow and fast MR scene renderings as documented in *4.2.4.3 Remote Scene Composing*.

4.2.4.2 Tangibles

Computer vision tracking for multiple tangible objects on a table, called tokens, can vary to some extent. This regards unique identification, appearance and shape of the tokens, as several recognition methods are possible. When using ARToolkitPlus[38]-based tracking, unique identification of all tokens can be realized. Each object on the table could be identified by a unique ID, and therefore the movement and orientation of the tangible object can be mapped to the virtual object (6 DoF), when assigned for one another (see Figure 43). The color and

Figure 42: User Interacting with a Tangible Color Token

38 http://studierstube.icg.tu-graz.ac.at/handheld_ar/artoolkitplus.php (04.10.2010)

shape based tracking of multiple tangible objects does not always provide a unique ID for each token on the table *e.g.* if there are two round red objects placed on the table the tracking component does not guarantee unique IDs, thus the IDs provided could be mixed up in two consecutive tracking events (see Figure 42). This issue could be solved by implementing a kind of tolerance radius around the last known location, allowing the situation to be stabilized, thus leading to unique IDs even for similar-looking tokens. As a solution had to be found for the situation in which it was unpredictable which ID within the same class of tokens was assigned by the tracking algorithm, all the virtual objects assigned to one class of tokens had to have the same appearance. This solved the problem to some extent, but occasionally introduced a little flickering in the renderings.

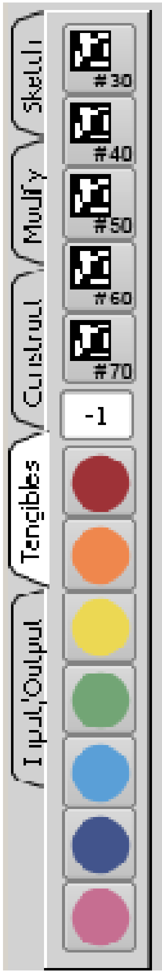

Figure 43: Tangible Assignment Menu

The integration of color and shape tracking of tokens *as* described in [96] imposed some constraints on the integration strategy, because the IDs of tokens were not unique, as mentioned. This means that IDs can suddenly change within one class of tokens. To address this issue, a management instance was implemented for organizing all tangible objects in the scene graph of Urban Sketcher. This integration approach allowed us to assign Urban Sketchers painting objects to tokens, so tangible manipulations and simultaneous painting on objects can be done. The ability to “clone” objects, which means that a copy of an object is created, which still shares certain parameters or abilities, was the solution for synchronizing all objects of one class, hiding the sudden ID change from the user for her convenience. If an object of the same class is modified, *e.g.,* painted with another texture, its corresponding clone would also change in the same way. Clones also have some individual parameters like their position.

The assignment of tokens to virtual objects can be done dynamically through an interface of Urban Sketcher. Available interfaces for that are either the graphics user interface (see Figure 43) or any remote device using the user interface API.

4.2.4.3 Remote Scene Composing

This solution is needed to be able to integrate the slower ColorTable rendering result in the rendering cycle of the faster Urban Sketcher rendering loop and has the advantage that the processing power of two computers contributes to the overall rendering job. Another advantage is that the development of both applications can continue without influencing one another too much. Remote scene composing allows the application to combine a remotely rendered scene with a local rendered scene including the depth information. This loose integration approach allows the application to combine the result from one rendering with another. If the remote rendering is slower, this has no impact on the rendering speed of the faster local rendering. A prerequisite for the scene composing is that the rendering is done from the same perspective in the scenes, so both, remote and local scene can be seamlessly combined.

Integrating the rendering of a remote (connected over 1 Gbit/s network) scene graph into the local MR scene including depth was a challenge. It required the creation of a new component for Studierstube, which comprised all the functionality needed to send the rendered scene from one scene graph to another, thereby uncoupling the rendering performance of the two applications: ColorTable and Urban Sketcher. The demand for correct occlusions in the combined scene and the support of the 5 viewing modes (*4.2.1 MR Views of the Environment*) made it necessary to stream the depth information in addition to the rendered scene and alpha channel which separates the scene objects from the video background, so locally generated background can be used with the remote rendered scene.

Several performance tests were performed in order to find an efficient way of encoding all the image data channels to be sent over the network connection while retaining near real-time speed requirements (30 fps) at low latency (1-2 fps) from end to end. As a result the M-JPEG compression was chosen for transmitting two RGB video channels (rendered scene and alpha channel) and four uncompressed channels for transmitting the scenes depth at 32 bit resolution.

In addition to the transmitting scene node also a receiving scene node was realized to sufficiently decode and integrate the incoming scene depending on the viewing mode. For network communication, the solution relies on a standard protocol (RTP) and an already available and established streaming library Live555[39] including synchronized streams, which is customized to support the needed transfer demands.

For synchronization of the rendered perspective all the camera parameters including field of view, position and orientation are synchronized, starting from the physical camera, if needed by the active viewing mode.

The core of the developed integration of transmitting and receiving a scene is also the basis for the dynamic scouting integration into Urban Sketcher. Automatic reconnection was implemented, as needed due to instabilities when using wireless network connections.

4.2.4.4 User Interface API

The user interface API was implemented so other applications like the ColorTable can remotely control Urban Sketcher's functionalities like, *e.g.,* changing the viewing mode using the barcode reader. Another motivation for the user interface API was to provide a simple interface allowing easy integration of any kind of device, which can extend the physical interface.

The configurable conglomeration of user interface components is designed to be open, offering an API based on Muddleware (MW) [165]. Many interactions offered by the graphical user interface can also be controlled by arbitrary devices or other applications. Furthermore input interfaces support integration of external content or entire streamed scenes, whereas the output renderings can be configured for various independent views.

The idea of MW is to provide a general framework for distributed offline communication of different participants. Data is stored in an XML database, which allows the usage of XPath queries[40]. Especially for a multi-device system, data synchronization can be carried out in an efficient way. One main feature is persistence of data. In combination with a specially written node for Studierstube, field connections between scene graph fields and the MW data base can be established. Values are synchronized automatically and therefore introduce persistence and easy remote access to fields in the

39 http://www.live555.com/ (04.10.2010)

40 http://www.w3schools.com/XPath/xpath_syntax.asp (04.10.2010)

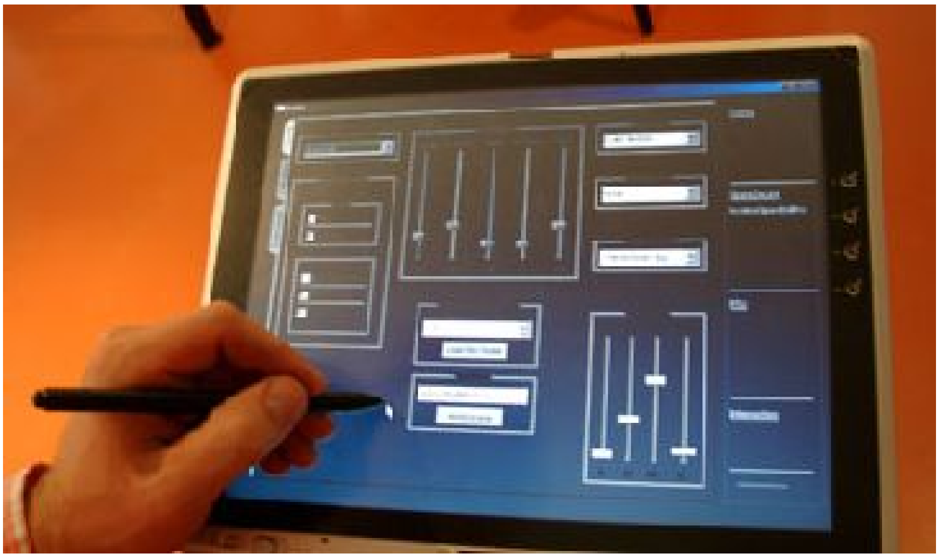

Figure 44: Graphical User Interface on Mobile Touch Screen

MR scene. Application or state-relevant values are saved and restored implicitly. The Muddleware API was introduced so the functionality of Urban Sketcher is available for other devices and applications via an open interface. Figure 44 shows a wireless connected tablet PC-based user interface for controlling application parameters via the MW API.

The *Muddleblob* component was developed to automatically receive content, like images or geometry files via the ftp protocol from various devices. MW is used for communicating content type, classification and location of the transferred data. The storage strategy is simply based on the operating system's file system. Received content classes can be inserted into the MR scene automatically and are then available for further interaction using tools of Urban Sketcher.

4.2.5 Simulation and development

Often simple scene mock-ups are used to simulate particular application states or interaction situations during development. In this way, runtime debugging is optimized for particular situations.

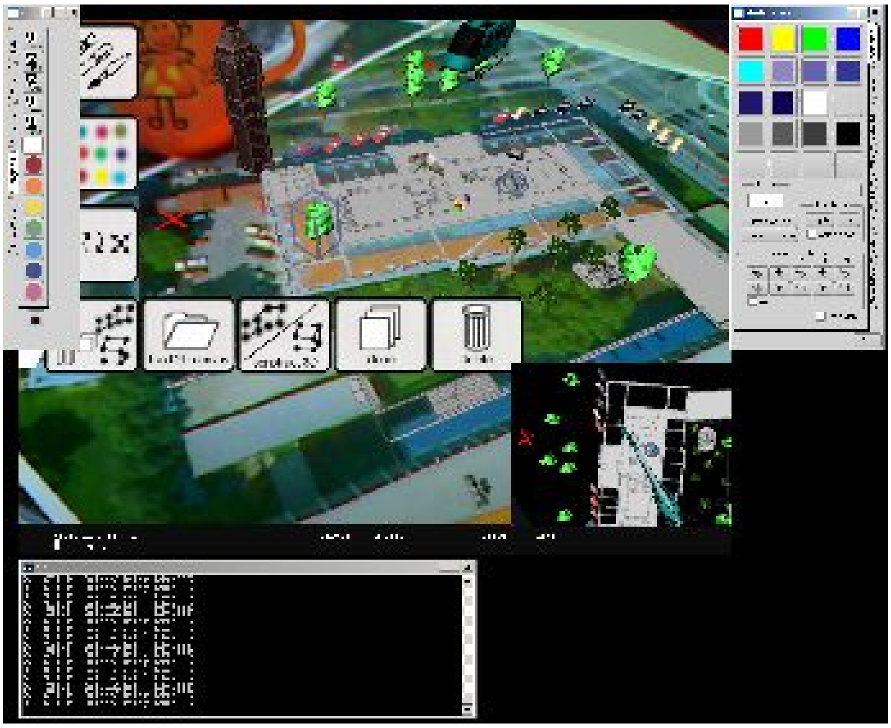

Figure 45: All Menus and Debug Consoles

In Figure 45, there are two places where debugging information is present in the output. One is the text console providing explicit debug output with many details of the running application. The other is the black section below the main rendering window needed more frequently. This section is used to give numeric feedback of viewer or object locations in the scene. In addition this output sends comments on just performed actions or confirms issued commands.

4.3 Visual User Interface Description

The graphic interfaces of Urban Sketcher are manifold, as direct 2.5D interactions in the MR Scene are combined with input from screen aligned 2D overlay menus. One menu is optimized for laser pointer and stylus input with large buttons comprising all common functions, whereas the the expert menu is designed with standard widgets and tabs.

Graphics interfaces provide a view into the MR scene from a chosen perspective, but also display feedback concerning tools and current operations, thus utilizing affordances. Moreover, they serve as portal for interactions combining 2.5D input and WIMP. The acronym, WIMP, stands for Windows, Icons, Menus and Pointing used for direct manipulation style user interface on the desktop, now adapted for spatial interactions.

In the following the two main graphical interface categories employed for Urban Sketcher are distinguished: the *4.3.1 Screen-aligned Interface* which overlays the perspective view into the MR space and the *4.3.2 Expert Menu* which consists of two separate windows with standard widgets next to the perspective MR view window (Figure 54).

4.3.1 Screen-aligned Interface

In Figure 46, four tools for sketching and painting on textures of objects in the MR scene are shown. The objects in the MR scene need to be defined by indexed face sets, texture mapping and a texture so they can be modified by the tools. Urban Sketcher provides some default flat canvas objects, used when images are inserted into the scene or when a transparent layer is needed for sketching.

Figure 46: Texture Manipulation Tools

Figure 47: Brush Color Options

The thin line tool is meant for sketching and has a sharp edge, the line width can be adjusted in the advanced menu (Figure 56) and the color can be defined in a dialogue or sampled directly from the scene with a pipette like tool Figure 47.

The color choices are the same for the air brush tool, the size and falloff can be configured in the advanced dialog (Figure 56). These settings also apply for the eraser tool, which removes the color and applies transparency. The texture tool can be used to apply colors from a separately selected image onto the object in the MR scene. In Figure 48 the texture selection dialogue is shown, where any image can be selected as brush texture for painting.

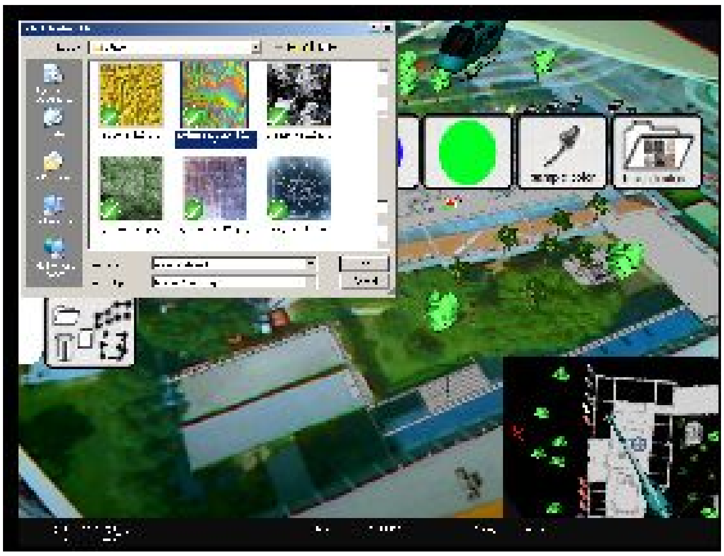

Figure 48: Texture Selection Options

Figure 49: Close up Canvas Painting

If an painting object is selected by clicking on it, its surrounded by a frame indicating its selection state. By pressing the space bar the selected object is temporarily moved close to the screen for editing as shown in Figure 49, where a part of the canvas was erased and the edge was painted blue.

Figure 50: Position, Orientation and Scaling Tools

In the third row of the on-screen-menu (Figure 50) the icons for activating the translation, rotation and scale tools are shown. The last row (Figure 51) allows the user to load and create content in the MR scene. The icon "*load 2D canvas*" opens a file dialogue so the user can select predefined canvas geometry files, which are loaded into the scene as canvas for sketching and painting.

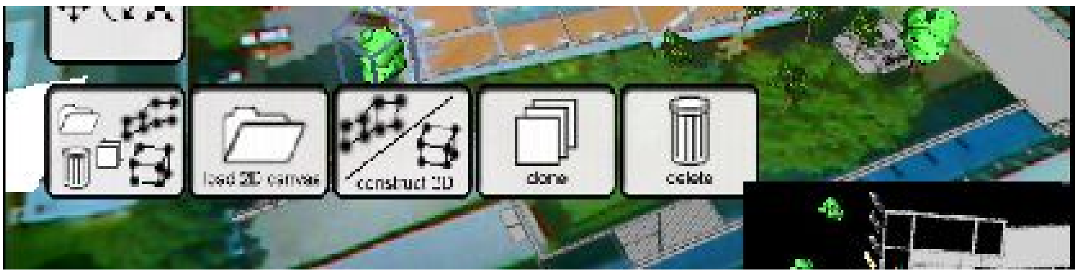

Figure 51: Object Inserting, Cloning and Creation Tools

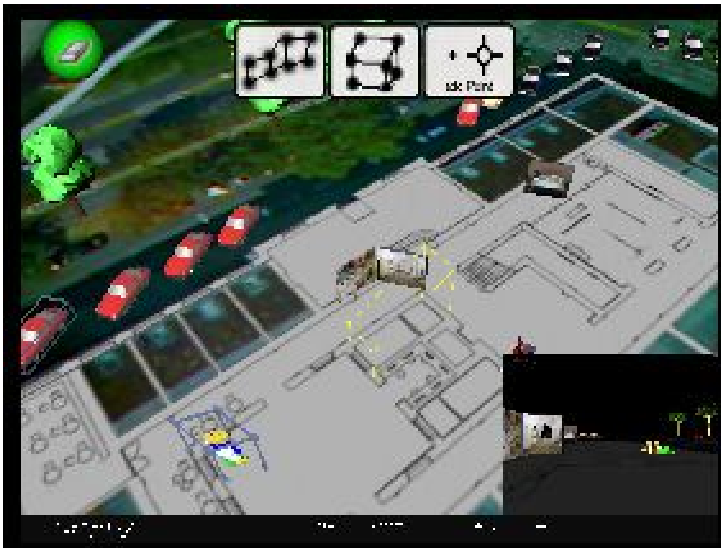

Figure 52: Constructing 3D Geometry

The “*construct 3D*” button activates the geometry generation mode. Once the mode is activated, three extra buttons are displayed at the upper part of the screen (see Figure 52), for generating simple polygon stripes or 3D objects directly in the MR scene. In order to start constructing, the user needs to indicate and “*click*” a point on the ground plane of the MR scene. A cross and an arrow will be shown. The arrow can be grabbed with the pointer in order to adjust the height of the first segment. Once the location and height are defined the “*add Point*” button must be clicked so the segment is added to the construction list. This procedure is repeated until all necessary segments are defined. The final action for generating the geometry

Figure 53: Result of 3D Geometry Generation

either the polygon button or the object button on the upper part of the screen is clicked to finalize the operation. The result is shown in Figure 53.

The clone button (Figure 51) creates a duplicate object of the currently selected object, which will always look the same as its counterpart even when the texture is altered by the tools. Like this *e.g.* a row of trees can be created. The delete button removes the selected object from the MR scene.

4.3.2 Expert Menu

The expert menu (Figure 54) is organized in tabs in order to efficiently use available screen space. In the “Sketch” tab, the icons resemble the ones in the screen-aligned interface and were explained in the previous section.

Figure 54: Expert Menu

The “QuickSet” tab comprises various buttons for color selection, a numeric input field for specifying the zoom value for the current camera, a button for inserting a new canvas in the scene using the current configuration in the “Scene” tab, another button is for inserting a screen-aligned canvas with the current configurations, a section of buttons is for handling phantom objects explained in *4.2.2 Phantoms, Occlusions and Layers,* some viewpoint preset buttons are for saving and recalling camera locations in the scene for testing purposes, and a lock view option box allows the user to freeze the tracking data for the virtual camera, resulting in a static camera position and orientation independent of any inputs. The Exit button closes the application and saves the MR scene, so it can be restored at the next start-up. The lock button is experimental and intends to lock objects in the MR scene, so they can not be changed anymore.

The buttons in the “Modify” tab (Figure 55) resemble the functions of the buttons in the third row of the screen-aligned interface, except for the scale button which activates the scaling for the current selected object with the slider below the button. The numeric input field is an offset factor for the scale value and the three check boxes are used to configure which axes are affected in the object space.

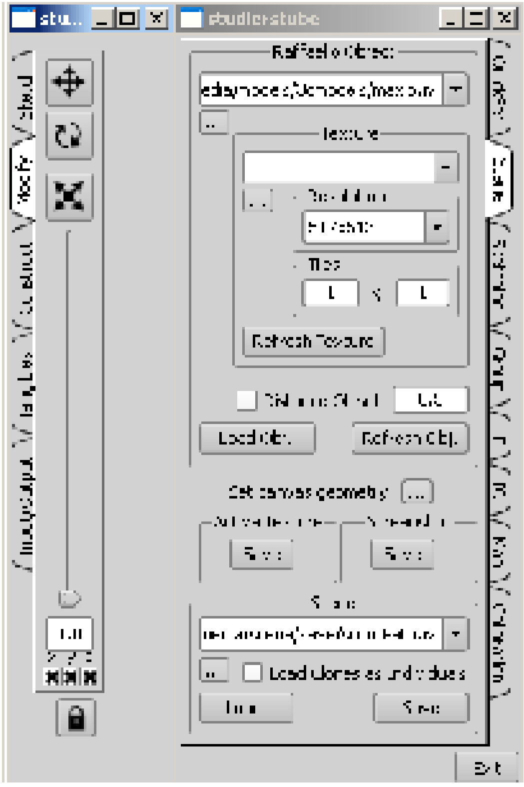

Figure 55: Expert Menu Modify and Scene

Any object which is inserted into the MR scene, using Urban Sketcher's user interface, is called *Raffaello Object.* And Urban Sketcher's user interface and tools can only affect Raffaello Objects. Any other scripted Inventor-based objects will only be rendered and are not considered for interaction by the UI.

In the “Scene” tab (Figure 55), the settings for new Raffaello Objects can be defined. The dropdown menus are meant for quick selection, the little button with the three dots should be used to open up a file dialogue for selecting a scripted inventor file, which should contain one well-defined geometry. If the object is intended for painting it should also contain texture mapping coordinates and a texture for the object. The section called *Texture* allows the user to define the texture of the Raffaello Object using the little button with the three dots. Textures can be either JPEG or PNG files. The *Resolution* drop down menu is used for selecting the texture resolution in the MR scene. This parameter can significantly influence the overall performance, which in addition depends on the graphics hardware used. Texture *Tiles* can be created by setting the values larger than one. *Refresh Texture,* is a button used for applying the texture to the currently selected object in the MR scene. The *Distance Offset* check box is relevant when new objects are generated using the

Load Obj. button. If checked, the new object will be located at a distance to the viewer (virtual camera), which is set in the numeric field. Otherwise it will be located at the scene origin. The *RefreshObj.* Button can be used to refresh the geometry and texture of an existing Raffaello Object. With the *Set canvas geometry* dialogue a default geometry can be defined for canvases.

The Active Texture *Save* button saves the texture of the current selected object to a PNG file. Screenshot *Save* creates a PNG file from the currently rendered MR scene.

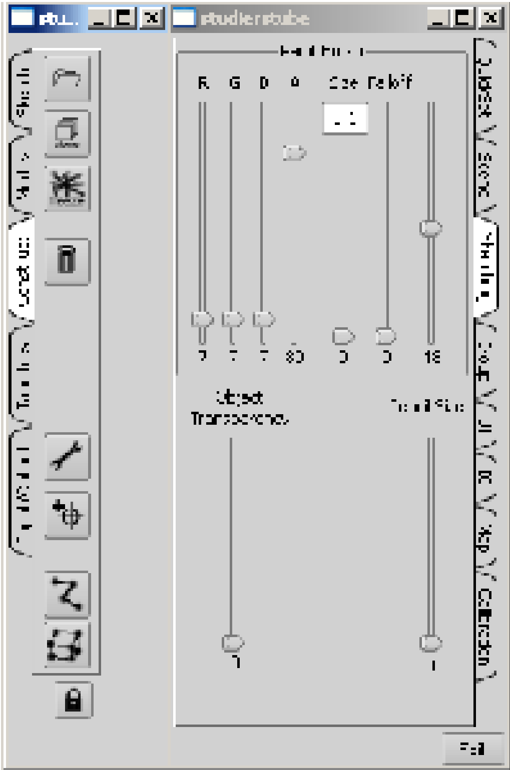

Figure 56: Expert Menu Construct and Sketching

In the section Scene, the path for saving and loading the whole scene as inventor script file can be altered. The Load and Save buttons are for loading or saving the whole scene. When the *Load Clone as Individuals* check box is checked, cloned objects are converted to normal Raffaello Objects.

In the "Construct" tab (Figure 56) the first button is for loading a Raffaello Object based on the current settings in the "Scene" tab. The second button is for creating a cloned object as described in the previous section. The freeze button disconnects all tangible tokens from their assigned Raffaello Objects. The button with the trashcan erases the currently selected object. The lower four buttons are for generating 3D geometry as explained in the previous section. The "Sketching" tab (Figure 56) comprises sliders for adjusting paint brush, sketching and object properties which are explained in the previous section.

The “Tangibles” tab (Figure 57) is explained in the section on *4.2.4.2 Tangibles*. The functions in the “Group” tab (Figure 57) are all in an unstable and experimental state. The dropdown box is meant for defining group names used for classifications. If the button *Add Active Obj. to Group* is clicked, the selected object is added to the indicated group. The button with the lock symbol is meant for locking/unlocking selection for the whole group. The next section in the user interface has not been tested and is considered as under construction.

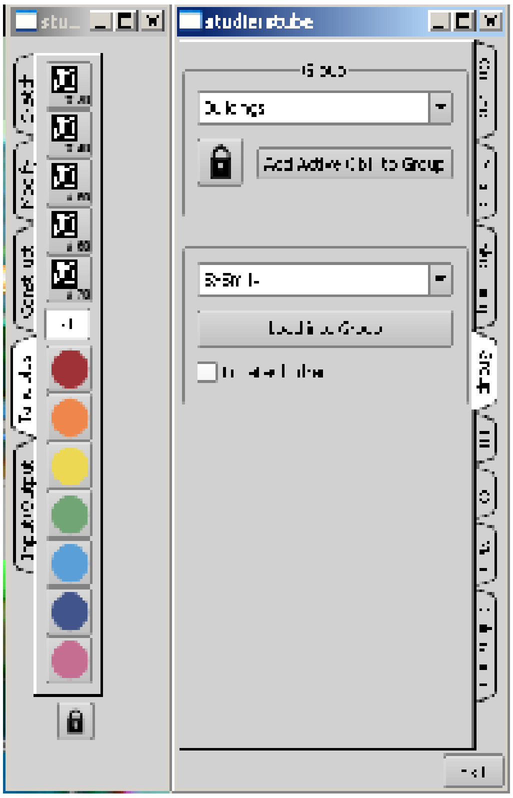

Figure 57: Expert Menu Tangibles and Group

In the “Input/Output” tab (Figure 58), the buttons are all shortcuts for already explained functionality and are considered obsolete.

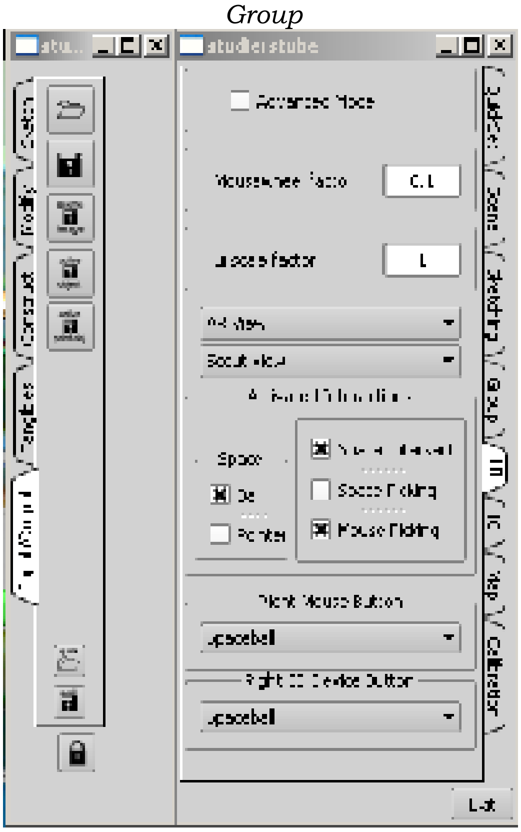

Figure 58: Expert Menu Input/Output and UI

The “UI” tab (Figure 58) begins with a check box which allows the user to toggle into an advanced mode. This was originally intended to better support experienced users. The only thing it currently influences is the object placement when new Raffaello Objects are generated, they are not constrained to a location on the ground plane, but are placed in mid air. The *Mousewheel factor* is not currently used and was intended as an offset factor for the mouse wheel operation. The two dropdown selectors are used for de-

Figure 59: Big and Small View Port

fining the current viewing mode for the big and small view ports (Figure 59). The different modes were described in section *4.2.1 MR Views of the Environment*. The section in the menu on *Activated Interfaces* is an obsolete functionality from an early development stage, where the user could define the preferred object selection mechanisms. Due to user preferences, mouse picking in the scene is always used as object selection method. The last two option boxes allow the user to define an action for the right device button.

The “IO” tab (Figure 60) is meant for adjusting primary settings in the context of managing content. The major Muddleblob functionality has been explained in the section on *4.2.4.4 User Interface API*. The UI is intended to support the development and debugging of the Muddleblob component. The “Watchdog” allows registration of object categories which will be automatically inserted into the MR scene if the filtering criteria are met. The *Media Root Path* indicates where the media files are located in the file system and the “IO Path” indicates where files are loaded from and are saved to.

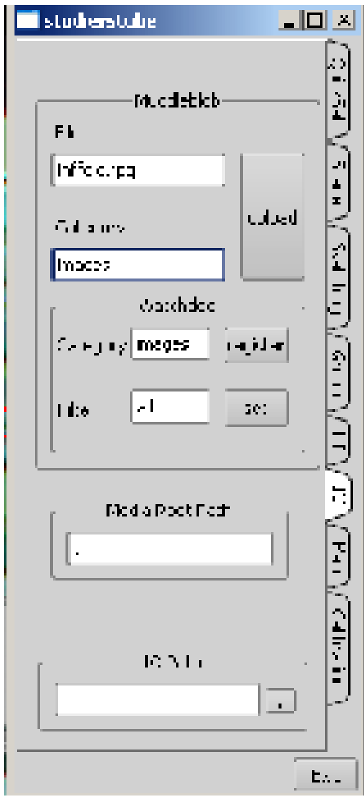

Figure 60: Expert Menu IO

In Figure 61 the “Map” tab shows all the offset and configuration controls for adjusting position, rotation and scale of the geometry as well as transparency of a map on the ground plane of the MR scene. Clicking on the “Map File” icon opens a file dialogue which allows the exchange of the map image on the ground plane. The section on Map Table is intended for offsets regarding the use of an additional map table component in Urban Sketcher.

The “Calibration” Tab (Figure 62) enables input for calibrating the viewer location in 6DoF, this initial step is needed for adjusting the coordinate system when using the *4.2.1.4 Pan-Tilt Camera Unit View.*

Graphics interfaces provide adjustable views of the MR-enhanced environment. Combined with an expert menu and screen-aligned interface, tools for sketching, painting and handling media content are available for users of Urban Sketcher to create and manipulate MR scenes using geometry and layers. Urban Sketcher integrates system components and interfaces. The implementations are based on experience gained in workshop experiments involving real-world urban development scenarios. Development stages and conducted workshop experiments are the subject of the next chapter.

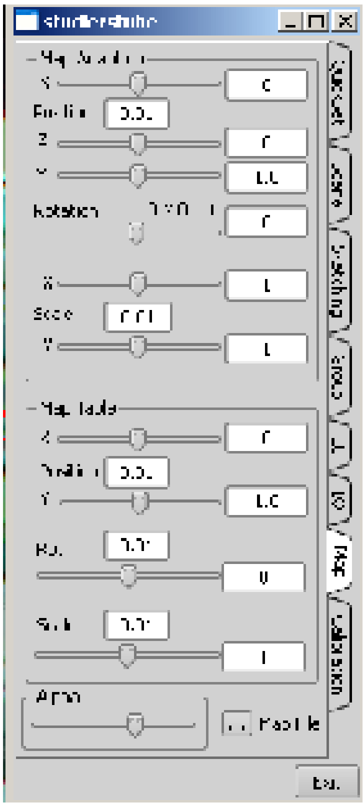

Figure 61: Expert Menu Map

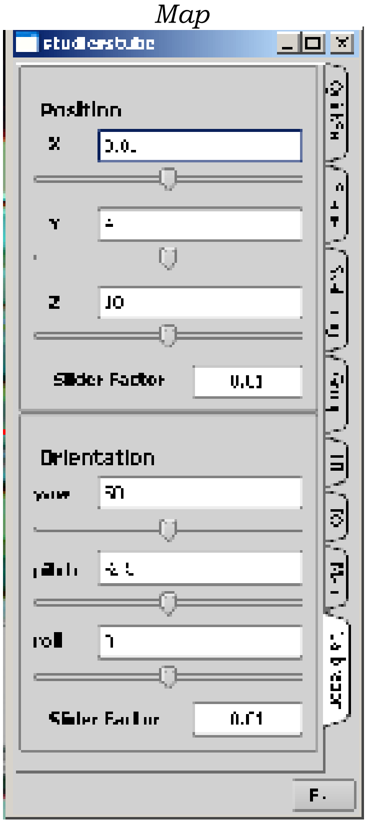

Figure 62: Expert Menu Calibration

Chapter 5

Workshop Experiments

Experiments and application of evaluation methods in combination with conscious observation are the foundation for obtaining substantial data and developing a sense for relevant facts and necessary changes. This process is needed for refining insights and gaining intuition in the context of a highly complex experimentation space as encountered in urban planning and reconstruction phases. Assessing insights involving intuition leads to new design decisions, crucial for the development process concerning mixing urban realities for both MR technology developers and the stakeholders in conducted workshop experiments.

In general, there are three types of stakeholders working and negotiating around urban projects: decision makers, designers and non-professional end users. They have different skills, different cultures, different relations to space and time, but also different relationships to technology. However, engagement of all stakeholders with their different backgrounds and experiences is needed for sustainable progress in urban planning and development work, expressing, identifying and communicating urban issues.

Urban planning is a work area that is successively a place of narration and sharing, a place of negotiation and decision and a place of co-conception and design. The traditional representation tools are efficient for designers, and are sometimes very powerful, but are not adapted to the collaboration including new actors allowing support for individual engagement of all people involved, so they can experience and express necessary information (*see 1.3 Urban Communication Processes*).

The development of new MR tools for the purpose of enhancing stakeholder communication in urban planning phases requires the assessment of usability and the evaluation of how well the stakeholders are supported in creating an MR scene, without disturbing the communication process itself. The MR scene leverages communication and serves by mediation and narration between the three families of stakeholders. Each one having her skills and responsibility, none having the capacity or the brief to replace the others, yet all are needed to work together, progress social values and achieve the common goal of understanding and consent regarding urban issues in phases of urban planning processes.

In order to observe and study stakeholders working with a specifically designed set of MR tools, in real-world situations on site, we designed the MR Tent (see *3.2 MR Tent*). We orchestrated several participatory, user-centered urban planning workshops, for sensitizing consciousness of participants and scientists. Participation in public events allowed the use of MR technology probes to enhance the environment without the constraints of an orchestrated urban planning scenario. Both types of participatory user-centered contacts contributed valuable experimentation information for the researchers to study.

Design insight and inspiration for advancing the development as well as making progress towards research questions was achieved by observation and personal communication with users during the deployment of several specially designed MR interface configurations outside the lab in real-world settings and scenarios, which were carefully orchestrated to address and inspire work with urban issues. These are described in the next section. The development and evaluation methodology employed is described in the subsequent section, followed by a section which summarizes all participatory workshops, events and occasions of user contacts with MR interfaces realized by Urban Sketcher. This includes the user impressions collected in the user-centered design processes. Finally a section summarizes design guidelines.

5.1 Urban Issues

A new emerging urban culture is challenged by highly complex interwoven urban issues and risks [15]. At the same time, a great potential exists for sustainable innovation, integration, social growth, conscious development and more happiness in society [46]. A increasingly volatile world[41] challenges responsibility, renewal and stability.

Wider participation and engagement in urban planning distributes responsibility and requires communication of urban issues at stake. In IPCity, we identified and summarized a number of urban issues, which are central in the exchange between the various types of stakeholders in their roles. Due to the vast variety of stakeholder roles and professional backgrounds, it is often difficult to understand one another, as each professional field involved seems to have developed communication codes and often its own understanding of central terms. Thus representation is one of the major urban issues.

Representation. This is a very important issue and plays multiple roles in the urban planning and development process. The communication within an urban project links and represents various negotiation phases (Figure 3). Actors engaged in the process represent their position, influencing the perception of others involved. A continuous communication process forms new ideas and insights into the project and inspires imagination of what could result from turning it into reality. New aspects and actors contribute to the development of the project which is being refined to ideally represent a common vision derived from the contributions. A new representation is developed out of other representations by actors who express ideas and visions using images, references, imagination, analogies, metaphors and languages in the urban multi-stakeholder arena to communicate possible effects before the urban project is built in reality. "*... the urban project needs to search for seduction by means of subjective images (evocating everyday life, imaginary,*

41 http://www.mckinsey.com/ideas/pdf/welcome_volatile_world.pdf (14.10.2010)

uncertainty…)" [167]. Representation communicates and develops visions. Technology contributes simulations of light, temperature, structural analysis, design, *etc.* to the representation of the project on the way from imagination to reality.

Representation itself deals with many other urban issues, often in a scene of controversy, with the need for negotiation and mediation. Understanding complex urban situations is a step forward where representation is an initial step introducing problematic aspects as well as solutions in the need for discussion and further refinement. Several cycles may be required for understanding, representing and refining finally leading to next steps or the next urban planning phase possibly involving negotiations towards decisions, thus making progress in the project. New MR tools are being designed to aid this process of mixing urban realities, learning from and building upon existing knowledge and traditional tools. The use of MR tools is embedded in urban scenarios aimed at negotiation for multi-actor city-making practices. Identifying and modeling concrete urban issues in a specific scenario is a challenge, as a multitude of dimensions influence the urban space. Influential urban issues were summarized by IPCity colleagues in a tech note and are not limited to:

- **temporal**
  - traces, archeology, uses of space, memories
  - life cycles - transformation and sustainability
  - maintenance and evolution of a site over time
  - urban rhythms – summer/winter, day/night
  - stakeholders short/long-term visions
  - time management
- **scales**
  - local/global
  - city and suburbs
  - metropolitan areas
  - large territories
- **mobility**
  - urban networks: internet, transportation modes and flows: metro, cars, pedestrians
  - new centralities: rail stations, commercial areas, leisure facilities
  - perception of speed
- **accessibility**
- **sensations**

    - physical phenomena: light, colors, sound, temperature, smells, air movements, climate
    - sensible perception:
        - physiological: 5 senses, sensitive systems
        - psychological: interpretation of sensations
    - social and cultural practices:
        - uses
        - behaviors
        - imaginative aspects
- **fuzziness**
- **borders**
    - legal, uses, public/private
    - collective/individual
    - representation/prestige
- **layers and boundaries**
    - in space and time
    - expertise, security functions
- **ambiance**

Numerous urban issues open manifold dimensions influencing the urban space. Most prominently, issues influencing the urban space are not always equally relevant for modeling a new perception of space in MR, as perception is an individual experience and issues depend on the concrete urban planning phase and situation. Selecting and highlighting certain issues helps to focus and concentrate the joined work in the urban context.

When working with MR in IPCity for representing urban space and in particular for representing specific issues, precision is not necessarily the goal (*e.g.* photo-realistic rendering), as *boundary objects* [161] are used to translate and abstract between dimensions, cultures and professional fields.

Describing and structuring individual human experiences, processes, states or behaviors in context of VR or MR environments is being explored and developed in the field of presence and engagement (see *2.2.1 Presence and Engagement*). The notion of presence and engagement in urban studies involves a range of currently used concepts identified and summarized by colleagues in [167]. Representation is as described in the beginning of this section.

Influences characterizing the notion of presence and engagement in urban planning and development concern the individual human experience, processes, states or behaviors in the context of the work with urban environments and are essential aspects when mixing urban realities. The development methods employed around workshop experiments, driving the various changing processes during the introduction of wider participation and MR technology used in IPCity and for progressing the MR application Urban Sketcher in several development cycles are described in the next section.

5.2 Development Methods

Development and evaluation methodology choice in IPCity for gaining insights into the highly complex experimentation space is a comprehensive approach. The problem can not be easily divided into discrete subspaces for study and evaluation with quantitative methods, because the urban communication process would be significantly influenced. The deployment of the MR Tent on site of urban reconstruction serves as a basis for multidisciplinary urban planning workshops. Urban planning professionals, architects, human interface design and communication specialists orchestrate real-world scenarios for conducted workshops. Participatory user centered design (see *2.2.2 Collaboration and Participation*) drives the development during a period (four years in IPCity). The iterative process of design-evaluation-feedback-redesign is instrumental for progressing the deployed MR technology probes [68]. Workshop scenario preparation involves analysis of the chosen situation selected from an ongoing urban planning phase. An initial meeting builds a working basis in cooperation with stakeholders and actors, who start to work with artifacts functioning as cultural probes [47]. The work with the probes triggers participation, identification and inspirational responses and allows participants to narrow choices for possible media content available for creative work with the MR scene in the later workshop. In addition this initial meeting is used to cultivate long-term communities of practice [175] around the discussed urban project.

During the workshops roles are clearly distributed. There are computer scientists, like the author, responsible for setting up, running and explaining MR equipment and interfaces, staff for recording and logging interactions, and workshop participants as urban planners, architects, officials, representatives and citizens who work together using the MR technology guided by urbanists and other experts. The qualitative data thus gained is rich in detail and available through subjective experiences, discussed right after the working phase in the MR Tent. Recording the workshop experiments on video tape is a common method to preserve valuable and rich data. Videotaping focused on the central ColorTable. Capturing the scenario from a meaningful perspective allows a detailed analysis of the recordings for gaining insights about workflow and interface design issues. Video and audio transcriptions are time- consuming, but can be fruitful if appropriate metrics are used for data extraction of repeatedly occurring events. The data collected from the final prototype was analyzed by the Viennese team [98]. A good introduction and guide for the art of coding groupware interactions is given by Nyerges *et al.* [121]. Complex mobile phone-based MR experiments were also conducted by Morrison and colleagues [112].

Interface design and evaluation as pointed out by Bowman *et al.* [27], the development of performance models as *"... important guidance for designers"* [27], is one approach to incremental development requiring an enormous amount of time for complex tasks. Starting in a real-world scenario involving urban development would need a very complex model and take more time than would be available for one project duration. *Formative Evaluation* [65] was used during initial developing stages of Urban Sketcher.

A *Summative Evaluation* approach, as suggested by Bowman *et al.* [27], was carried out in order to scrutinize interface design insights concerning bimanual handheld user interfaces realized with Urban Sketcher in a user study (see *6 Bimanual User Interface Study)* specifically designed with experience gained from previous scenario workshops. The common and applied tool in this more laboratory type evaluation context is the statistical analysis of the gained data using multivariate techniques to outline characteristics and significance of parameters and design choices concerning Urban Sketcher's basic usability. A good basis reference on statistical analysis is the well explained book by Hinton and Hinton [64].

The conducted urban communication workshops were used for co-designing MR technology and developing design guidelines. Multiple actors engaged in participatory design of MR tools for decision making in real-world scenarios [11]. Interface design decisions based on workshop evaluations require multidisciplinary intuition and a trained sense in order to make significant progress with mixing urban realities, essentially leading to improved inter-human communication.

5.3 MR Interface Designs

User interfaces mediate communication between engaged users with the instrumental collaborative information space represented by the MR scene. Their design strategy is strongly influenced by the introductory research questions and user feedback and must undergo a continuous cycle of development evaluation and redesign, learning from the various research communities involving MR, AR, HCI, CSCW, Presence, Design and others.

Components of Urban Sketcher contribute interface parts and provide hardware device connections, which can be partly scripted to design the MR interface.

The application development is driven by user-centered design from urban reconstruction scenarios and public events, but is not limited to a particular field. Communication aspects involving the public, namely anyone who wants to engage in mixing realities processes, are considered to be valuable. If a specific user target group or workflow is to be addressed, the interface design might focus on giving more weight on certain aspects leveraging efficiency.

Real-time capability is a very important factor, as noticeable lags or jerky, non-fluent information presentations or slow tool feedback impose unwanted disruptions, leading to extra cognitive load on the user, thus negatively affecting communication efficiency. This requirement should implicitly be considered when designing synchronous MR interfaces [102]. On the technical side, it is one of the most difficult requirements, as newly integrated features or components as well as large MR scenes influence overall system performance. Three key values were empirically found during participatory events to define perceived borders and seams of various types. One is the rendering and update performance, which should always be well above 30 fps. Another one is the sampling frequency of the hand-operated input devices for sketching operations, which should be around 100 Hz. A delay of 1-2 frames is irritating, but acceptable in some cases. Designing with these values in mind reduces disruptions, synchronizing the digital and real world for human perception.

A central round table is an established real world tool for communication, whereas the quest for the optimal display of an MR scene on the table is still ongoing. Tracked HMDs can augment individual stereoscopic viewpoints of the scene [111], but restrict the free movement and direct eye contact, thereby imposing constraints on the communication process. In contrast, fixed monoscopic MR displays can present information simultaneously to all collaborators from the same point of view, establishing a common base for eye-to-eye discussions, which are rich in communication cues, but lack immersion and ego-reference.

The combination of a central round tangible table and an interactive wall-mounted screen (see *3.3 MR Technology*) was tested and well received by urban workshop participants. The table surface is used to represent the ground plane of the MR scene and to provide interaction space for tangible objects on a map, whereas the wall-mounted screen allows the user to present perspective egocentric and exocentric views into the collaboratively shared MR scene and serves as direct-interaction portal for laser pointer input.

Design stages of the spatial, physical and graphics development concerning the user interface are part of the following section which lists all participatory events and workshops.

In addition Chapter *6* on *Bimanual User Interface Study* compares two potential MR interfaces in a user study aimed at helping the interface designer to scrutinize design decisions within an promising design space.

5.4 Participatory Events and User Contact

This section summarizes all events where Urban Sketchers MR interfaces were set up by the author to engage users. The events are in chronological order, so consecutive progress stages become obvious and can be described. User-centered design development was driven by communication and experience made in real-world application situations. The mapping between realities allows to observe user actions involved in collaborative and single-user tasks. Creating and changing the MR scene, using available tools allows the users to playfully connect imagination with reality and communicate with the support of the mediating MR scene.

In any case, communication and awareness are essential for decisions leading to new challenges. The involved user groups were deliberately varied to a great extent, as it is necessary to engage urban planners, architects, investors, technical specialists, community politicians and citizens in a social process of mixing realities in order to achieve an amicable solution for topics at stake and mutual understanding concerning urban issues and the future.

A table in the beginning of each described event outlines the type of event, date, location and number of participants. Participating user types are mentioned as well as objectives. The deployed interface and MR scene for the event is described and finally gained insights and observations are summarized.

5.4.1 Initial Probes at Saint Anne Hospital

Event Type	Indoor Workshop
Date	15. June 2006
Location	Saint Anne, Paris, France
Participants	20 + 10 IPCity
User Types	urban planners, architects, hospital professors and staff, computer scientists
Objectives	present marker-based MR technology probes, show space device interaction, understand local planning issues, identify central communication situations
Interface/ MR Scene	ARToolkitPlus tracked scene, 6DoF space device, textured canvases, augmented balcony wall outside the venue
Observations	MR is suited for working with this scenario, universal and simple interaction tools and interfaces are needed, painting of canvases suggested for more detailed scene modifications

The first workshop in Saint Anne served for introducing the basic concept of augmented reality to a group of stakeholders and planners concerned with the reconstruction of the Saint Anne Psychiatric Hospital. The wall of the balcony served as a dummy for the wall enclosing the mental home, which is under discussion for reconstruction, as the relationship between the inside and outside is considered to be opened up to some extent. Several suggestions and visions exist for a new design of some wall sections as well as controversial interests regarding the future "openness" of the wall.

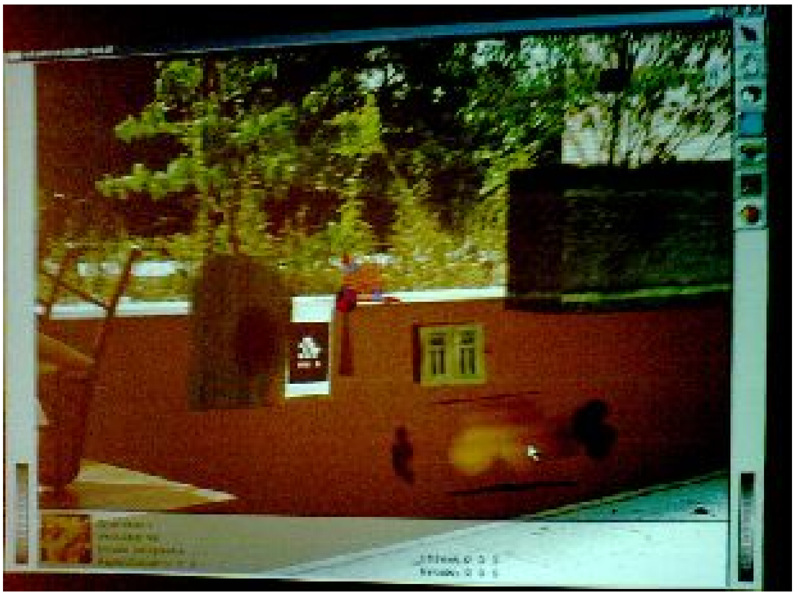

Figure 63: ARToolkitPlus Tracking for Augmented Balcony

Figure 63 shows how some green sections and windows were placed on the wall using textured canvases, suggesting the use of MR technology for altering reality, thus supporting the ongoing debate of the real-world scenario.

The situation in this workshop was orchestrated by urban planners reflecting an early stage in the planning workflow. Stakeholders in the context of the re-planning gathered on site, so the collaborative planning scenario could be observed. Furthermore they were invited to comment on the presented MR scene and its usefulness for aiding their communication needs in this particular planning phase.

Figure 64 shows a situation in which an urban planner expresses his vision and moderates the ongoing discussion about the reconstruction. As a result three important communication situations were identified.

- First, the moderation of the communication processes.
- Second, the need for individual support when expressing a point of view.
- Third, the need for multiple simultaneous information access and possible interaction with it.

The central topics in the workflow are related to urban and architectural design involving urban issues, thus ideas of geometrical relations, accessibility and ambiances as well as temporal or material aspects.

Figure 64: Urban Planner Moderating and Explaining the Site

Positive responses from the stakeholders and planners led to an invitation to conduct another workshop directly on the reconstruction site, so work can be done directly in situ with the real wall in conjunction with neighborhood representatives and other parties concerned.

5.4.2 Vienna District 16 Urban Renewal Office

Event Type	Indoor Workshop
Date	25. September 2006
Location	District 16, Vienna, Austria
Participants	15 + 10 IPCity
User Types	urban planners, architects, sociologists, authority representatives, computer scientists
Objectives	present early MR technology probes, observe urban planning communication habits
Interface/ MR Scene	optically tracked stylus, augmented neighborhood outside the window of the office using PTCU (see *3.3.4 Pan-Tilt Camera Unit*)
Observations	intuitive mapping of MR scene and interaction space needed, interface responses too slow for painting and interactive view changes

This workshop was conducted to study the stylus-operated interface in a real setting on a reconstruction site. Participants in this workshop were members of the urban renewal office, as well as two collaborating architects, an urban sociologist, and two representatives of local authorities. The collaborative situation with people involved in city planning showed how particular issues are communicated and ideas as well as problems are shared among one another. The proposed MR interface was difficult to use for non-experts, but showed the idea of augmenting the real environment with sketches and paintings; see Figure 65.

Figure 65: Expert Painting with 3D Cursor (left) Setup (right)

The spacial relationship between interaction space, screen and MR scene were not oriented in the same direction, this led to an extra mental load for imagining the transformation necessary for mapping the interface in the right direction. As a result, taking previous laboratory observations into account, the decision was made to use a picking mechanism for acquiring the right location in space for applying paint on objects in the MR scene. Basically one can imagine a ray going from the stylus to the screen and from the screen into the augmented space until it intersects with an object. This approach will map hand movements directly to the perceived MR space.

5.4.3 TU Graz Open Lab Night

Event Type	Indoor Open House
Date	09. October 2006
Location	Institute for Computer Graphics and Vision, Graz, Austria
Participants	50
User Types	students, citizens
Objectives	present initial laboratory development setup, explain and observe canvas painting-based interface handling
Interface/ MR Scene	optically tracked stylus, augmented walls of the laboratory
Observations	direct spatial relationship between MR scene and interaction space needed, interface responses too slow for fluent painting

Figure 66: Initial Painting Interface Laboratory Setup

The initial event for testing the painting interface was a laboratory setup which was also presented at the open lab night. The public was invited to try out a rudimentary interface design for painting canvases and visualizing their ideas in collaboration utilizing the MR space. The spatial mapping between the stylus and the MR space was experimental and had not yet direct 1:1 geometric relation at this implementation stage (Figure 66).

In Figure 66, the interface operation is demonstrated to some interested users who provided valuable feedback on how the stylus device could control the 3D cursor at some distance from the screen which seems to be favorable.

5.4.4 Institute at Vienna Karlsplatz

Event Type	Indoor Workshop
Date	01. December 2006
Location	Institut für Gestaltungs- und Wirkungsforschung, Vienna, Austria
Participants	10 IPCity
User Types	urban planners, architects, computer scientists
Objectives	explore direct screen-based stylus interaction, explain and observe interface handling
Interface/ MR Scene	optically tracked stylus, PTCU-based scene tracking and view navigation, augmented urban space outside the window
Observations	stylus mapping and interaction is useful, interface responses far too slow for painting, more MR tools for easy media content manipulation needed, introduce thread support for painting

Figure 67: Architect and Urban Planners (right) MR Scene (left)

Urban planning professionals and architects gathered in an informal collaborative situation, to test interface configurations and discuss features for possible tools which could aid the communication process regarding reconstruction sites. In Figure 67, one architect took the interaction role while being instructed and observed by the others. The stylus interface at this stage supported picking and created a direct relation between screen and stylus position.

Figure 68: Space Device

Important tools were considered to facilitate intuitive moving, rotating and scaling of objects in the scene and allow the insertion and painting of 3D geometries and pictures. Also the overall interface should advance in a way that also novice users can easily play with the displayed MR scene, thus supporting their creativity to visualize ideas.

Early interfaces were designed to be handled by experts, as the user interface could not be operated without any training. The spatial interaction with objects in the scene graph was based on the simultaneous input of 6DoF using a space device (see Figure 68). Typically this device is used in a bimanual way in combination with a classical mouse. This solution implied a high cognitive load for mental mapping on the user, preventing her from actively participating in any collaborative communication activities and is only considered for debugging and as a fallback solution in special cases.

The performance of the application was found to hinder interaction when painting, thus limiting the user's movement and intended working speed. This temporal seam blocks fluent communication and was considered to be a major issue, thus implementation changes are needed. A proposed solution is to implement multi-threaded painting, allowing efficient use of threading CPU capabilities as well as multiple CPU cores.

5.4.5 IPCity Review Sankt Augustin

Event Type	Indoor Demonstration
Date	26. February 2007
Location	Fraunhofer Institute for Applied Information Technology, Sankt Augustin, Germany
Participants	10 + 20 IPCity
User Types	urban planners, architects, computer scientists
Interface/ MR Scene	phantom objects, space device, go-go interaction, PTCU-based tabletop model augmentation
Observations	precise PTCU calibration for indoor tabletop use required

Figure 69: PTU Tracked AR Setup

The interesting aspect of this AR setup is the tracking, as no natural feature tracking was available for computing the 6DoF of the camera location in real time at that time and no fiducial markers were laid out on the map for tracking. After an initial calibration step, the location was computed from the inherent transformations of the PTCU holding the camera. It was found that this solution can be useful, but is very sensitive to offsets and needs a precise calibration, especially when using the camera zoom, as the zoom value is not measured directly, but instead is computed, based on some approximations. The PTCU tracking, although not perfect, was considered to be sufficient for outdoor situations. The advantage when using the space device is the spatial freedom allowing users to place objects anywhere in the augmented space as depicted in Figure 69, where textured canvases (project logo, castle) were placed in the background. For convenience, the go-go interaction technique [131] was implemented allowing users to easily reach distant locations with the space device. The 3D cursor controlled by the device is visualized as an arrow in the MR scene (lower left part of Figure 69) and gives the user feedback about its current distance.

5.4.6 Saint Anne Wall Scenario

Event Type	Outdoor MR Tent Workshop
Date	19. March 2007
Location	Saint Anne, Paris, France
Participants	25 + 12 IPCity
User Types	urban planners, architects, director, manager, urban sociologist journalist, sound specialist, public representatives, computer scientists
Objectives	MR technology and tent layout trial, apply MR probes in real-world scenario
Interface/ MR Scene	expert interface for inserting, texturing and painting, canvases and 3D geometries, PTCU-based scene tracking and view navigation, image scout, augmented urban space outside the tent
Observations	painting interface and tools for novices and experts needed, object buttons useless, technical specifications for MR Tent design scrutinized

The second workshop in Saint Anne was conducted on a real reconstruction site with a temporary tent enclosing the MR technology probes. Figure 70 depicts the tent and interface environment of the workshop.

Figure 70: First on Site Tent Setup

Citizen representatives, stakeholders, architects and urban planners gathered in the real-world planning scenario for reconstructing the large wall around the mental home to be more open. The controversial points of views concerning the future design of this partly public space were typical for this planning phase, as stated by an urban planner. The workshop was connected to the "City on the Move" event with the title: "*The street belongs to all of us!*"[42].

Two topics were debated, first the visualization of the future wall (Figure 71) was influenced by varying interests of the participants, second the design of the MR interface (Figure 72).

Figure 71: Debating on the Future Opening of the Wall

42 http://www.larueestatous.com/index_uk.html (06.10.2010)

Figure 72: Discussion in the Provisional Tent

"*The chief architect R., for example, saw the Urban Sketcher as the more accurate tool – 'with the screen it's easier, because you have already the proportion, you have already the translation, the correct scale'.*" [99] It became clear that individual expression is important for the overall communication process, and the MR interface needs to support users with varying levels of experience so they can actively engage themselves by interacting with the MR scene.

A scout is a person using some equipment to transmit information from the environment to the tent. The introduction of the scouting idea was considered to be very useful by the urban planners, who instantly asked if its capabilities can be extended to provide a live

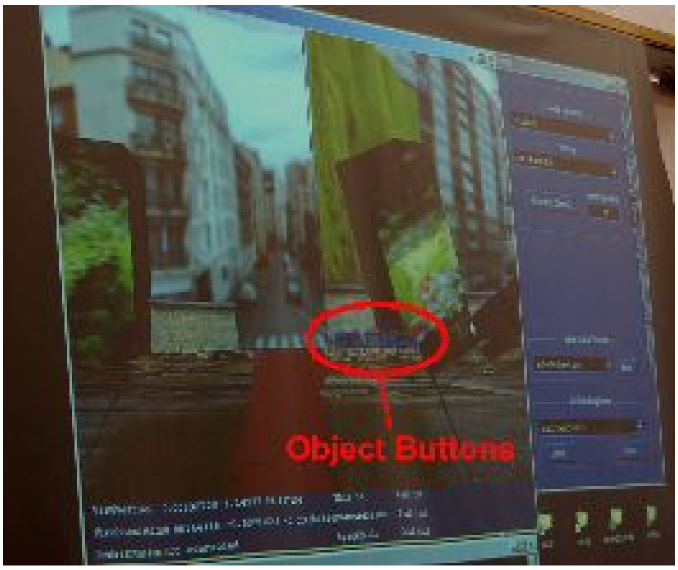

Figure 73: MR Scene with Active Object Buttons

video stream from the environment to the inside of the MR Tent. At the current implementation stage, the wireless transmission of images right into the MR scene using a WLAN connection was supported.

The applied object buttons (Figure 73) for moving, scaling or accessing other object options on canvases and 3D objects appeared to be of little use, as they were often out of reach or covered by other objects, thus unreachable when needed. A new interface solution for handling object interactions is required. A requested feature was the introduction of depth information of real world objects so occlusions are handled correctly in the MR scene and is important to communicate spatial relations. The author's first publication on Urban Sketcher [150] reports about this workshop and the implementation of phantom objects. Their use and interface is described in section *4.2.2 Phantoms, Occlusions and Layers*.

5.4.7 Peach Summer School Demonstration

Event Type	Indoor Demonstration
Date	04. July 2007
Location	Nomikos Conference Center, Fira, Greece
Participants	60
User Types	students, presence and computer scientists
Interface/ MR Scene	screen-aligned buttons, spatial ARToolkitPlus tangibles (*4.2.4.2 Tangibles*), webcam-based indoor augmentation
Observations	very large markers required for distant spatial interactions

The summer school in Greece was mainly focused on presence technologies and fundamentals. The event encouraged team work and creativity, bringing together researchers and students from many academic and industrial disciplines.

Figure 74: Laptop-based MR Demonstration

Figure 74 shows a snapshot of the live demonstrated MR setup. The augmented hall of the Nomikos Conference Center is visible on the laptop screen. Large ARToolkitPlus markers were used to engage users with real-time interaction. The markers were moved in real-world space with virtual objects attached, the resulting MR scene was visible on the laptop screen.

5.4.8 Exhibition "Draußen in der Stadt" (Outside in the City)

Event Type	Indoor Workshop/Exhibition
Date	04. September 2007
Location	City Exhibition, Vienna, Austria
Participants	25 + 8 IPCity
User Types	urban planners, city officials, public space developers, computer scientists
Interface/ MR Scene	optically-tracked stylus for on-screen input, PTCU-based outdoor augmentation of urban space
Observations	discontinuities when painting, need to separate and hide advanced interface features (keep it simple)

This indoor setup was used to augment a large public space in front of the building where the exhibition took place. The on-screen interface was mainly used for moderation purposes and as the common focus for a presentation on general urban issues and negotiation phases by an urban planning professional.

Figure 75: MR Setup at the Exhibition

In Figure 75, the configuration of the MR interface is shown. The PTCU is “looking” outside the window for the live augmentation. Advanced bimanual interaction with a mouse for object selection and a

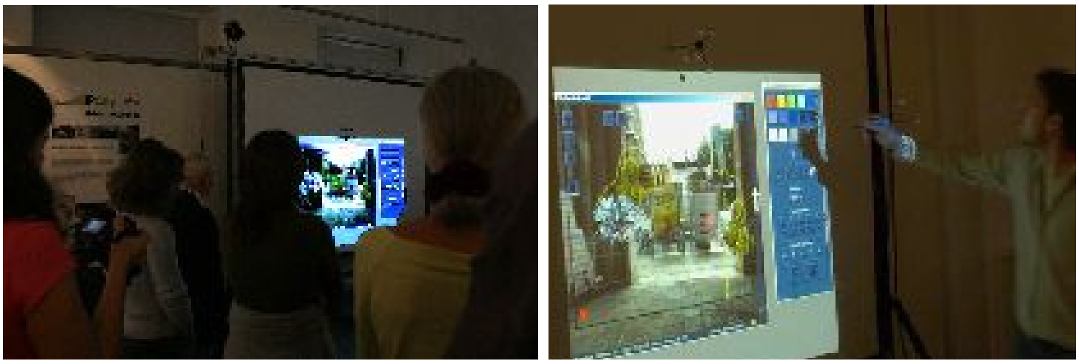

Figure 76: Visitors Experiencing MR-augmented Public Space (left) Screen-based MR Scene Manipulations (right)

6DoF space device for placing textured canvases into the MR scene was performed as a preparatory step. As a result, it was found that the advanced interface and its features are needed for orchestrating and setting up an MR scene, but should mainly be hidden for casual users, so less visual clutter is present on the screen.

Figure 76 (left) shows the audience during the presentation moderated by an urban planning professional. Figure 76 (right) visualizes the placing of textured canvases and sketching on them in the MR scene. The stylus-based input on the screen seems to be the reason for event discontinuities when painting or sketching, resulting in strange interface responses. The cause needs to be further investigated in order to achieve fluent interactions.

5.4.9 Paris TGI Scenario

Event Type	Indoor Workshop
Date	18. September 2007
Location	mk2 Cinema Complex, Paris, France
Participants	12 + 10 IPCity
User Types	urban planners, ministry officials, residents, sound specialist, computer scientists
Interface/ MR Scene	optically tracked stylus for on-screen input, 3D architectural models, PTCU-based outdoor augmentation of urban space
Observations	stylus interface not fluent – introduce laser pointer-based interaction, application integration of the ColorTable suggested

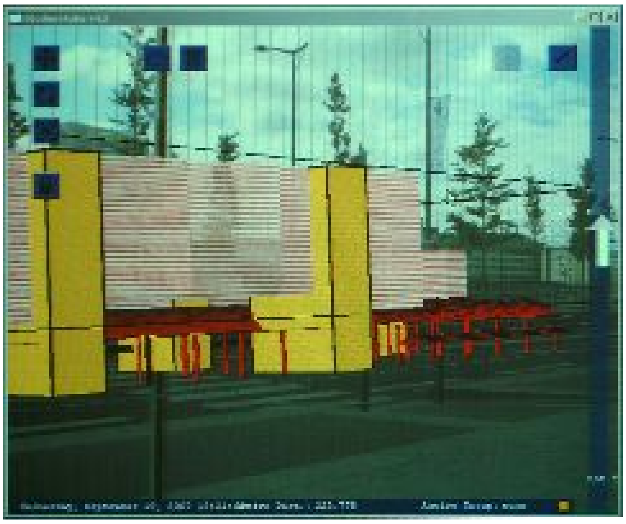

Figure 77: MR Scene with 3D Models

The on-site workshop was setup indoors inside the newly built movie theater mk2. The transparent wall on one side of the building directly faced a reconstruction site, right in front of the French National Library. In a contest, architectural students designed virtual models of the future urban site. Three different designs were chosen to be placed and evaluated on site using an interactive augmented representation with Urban Sketcher (see Figure 77).

In Figure 78 (left) the setup is shown. The PTCU was placed in front of a window to overview the reconstruction site for augmentation. Figure 78 (right) shows the introductory demonstration of the screen-based interface. It is intended for a wide range of users with varying experience. At this development stage it is still partly dependent on input from the expert menu, thus not completely optimized for intuitive use by novice users. All run-time application settings, options and tools are available in the expert menu, designed with classical 2D user interface widgets. This menu was extended

Figure 78: MR Setup and Interface Demonstration

Figure 79: Expert Menu and Screen-aligned Buttons

as more components were integrated Figure 79. A number of choices and tools need a large display space, so tabs were introduced to multiply the available space. To avoid too many menus on the screen, the advanced menu can be hidden using a keyboard command. The screen aligned buttons are always visible on a static screen position, disregarding the current viewing location in the MR scene. In Figure 79, an early interface design is shown, where the buttons and the slider on the right make frequently needed tools instantaneously available. The downside of this approach is that the view is partly obstructed and user attention might be distracted.

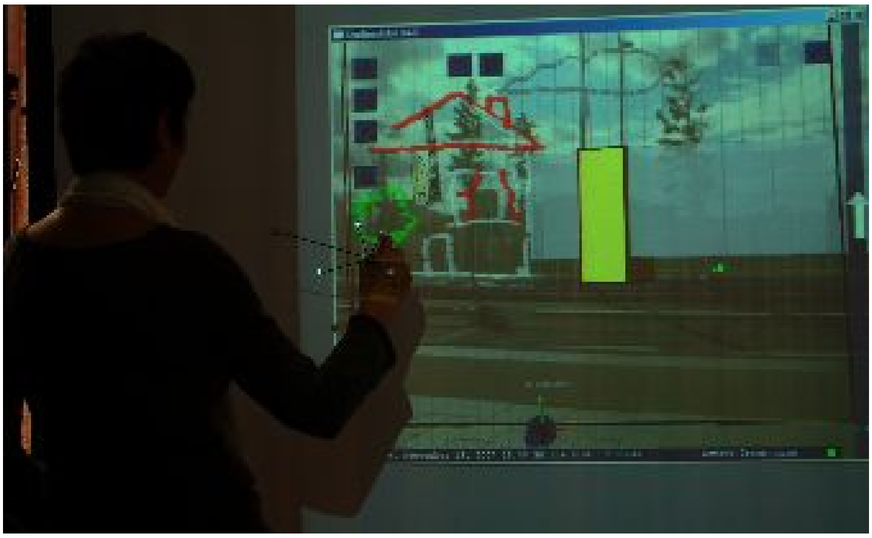

Figure 80: Sketching Next to an Imported 3D Model

Controversial points of view regarding the reconstruction of the site were expressed by an engaged workshop participant, who sketched her vision next to the 3D architectural model (Figure 80). Sketching in a scene means connecting for the user what she imagines with what is there. The advantage of "*live*" sketching is that participants witness how the sketch develops and changes in the scene happen. While sketching, participants create spatial collages with several layers of canvases which can be positioned upright prominently on the ground plane in urban space. They discover the possibility to systematically work with layers and transparencies, thereby lending depth to the scene [151]. The viewing perspective into the projected MR scene can be altered with a wireless joypad by changing the orientation of the PTCU facing towards the reconstruction site.

Figure 81: Communicating MR Interface Experiences

The moderated discussion on the experiences with the MR tools and their future design followed the communication and planning scenario on urban issues (Figure 81). The performance of the stylus input was found to hinder interaction when painting, thus limiting the user's movement and intended working speed. This temporal seam blocks fluent communication and was considered to be a major issue, thus implementation changes are needed. It was found that the wirelessly transmitted button states and resulting events were responsible for disruptions. Another suggested interface improvement for the next urban planning workshop concerned the optically tracked stylus, which sometimes lost track due to shadows and occlusions caused by the user. Furthermore, the limited tracking range right in front of the screen prevented the user from gaining an overview of the displayed scene while interacting from some distance to the screen. The suggested use of a laser pointer as input stylus, thus allowing interaction near and at distance from the screen was considered to be a good solution (see *3.3.3 Stylus / Laser Pointer Input*).

When the 3D models of the students were converted so they could be inserted into the MR scene, it was found that a lot of effort is needed by an expert to adapt them, as they were created with respect to high detail and fidelity, which needs to be changed for real-time rendering. The integration of the ColorTable application was suggested for the next workshop, so functionalities can be used in combination with Urban Sketcher.

5.4.10 ISMAR 2007

Event Type	Indoor Conference Demonstration
Date	15. November 2007
Location	Nara Prefectural New Public Hall, Nara, Japan
Participants	50
User Types	MR and AR experts, computer scientists
Interface/ MR Scene	interactive viewport selection with webcam, mouse operated on-screen interface, phantom model and canvases for occlusion handling, ARToolkitPlus multi-marker tracking of tabletop miniature model
Observations	precise dynamic 3D object occlusion handling requires high computation power for real-time detection and rendering

A tabletop miniature model was chosen to demonstrate the published results [150] of painting phantom layers and creating phantom objects of the miniature model (see *4.2.2 Phantoms, Occlusions and Layers*). Interacting with media content in the MR scene demonstrated the correct occlusion handling. A webcam and ARToolkitPlus were used for tracking the augmented viewport of the plain 3D model and for tracking tangible markers. In Figure 82, a user is playing with the interface and comments on computer vision

Figure 82: Tracked Model with Tangible Fiducial Marker

issues when one wants to handle occlusions of dynamically changing real-world objects. An approximation of this situation was shown using a tangible marker for tracking the real-world location which had a phantom canvas attached to it. The canvas was painted to represent the silhouette of an object near to the marker.

5.4.11 IPCity Review Barcelona

Event Type	Indoor Demonstration
Date	25. February 2008
Location	Universitat Pompeu Fabra, Barcelona, Spain
Participants	10 + 10 IPCity
User Types	urban planners, architects, computer scientists
Interface/ MR Scene	interactive view port selection with webcam, mouse operated on-screen interface, phantom model and canvases for occlusion handling, ARToolkitPlus multi-marker tracking of tabletop miniature model
Observations	mobile computer sufficient for fiducial tracking and inserting and placing content

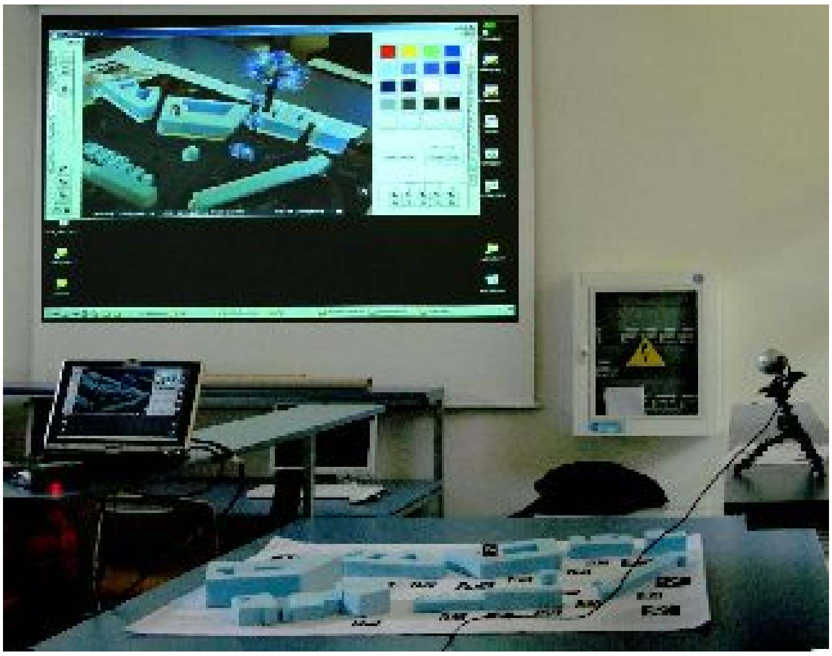

Figure 83: Augmented Tabletop Model Tracked by ARToolkitPlus

In Figure 83, a complete setup with a tabletop model is shown. For simplicity, the tracking works with fiducial markers. The performance of this setup was still acceptable for inserting and locating content with a tablet PC (Pentium M processor). However, the texture painting did not work as fluently as required for an interactive communication situation. This is not surprising, as the CPU-based painting implementation of Urban Sketcher is optimized for multithreading targeted at multi-core high-performance computer architectures.

5.4.12 MR Tent Prototype Trial

Event Type	Outdoor Trial
Date	28. April 2008
Location	Campus TU Graz, Graz, Austria
Participants	15 IPCity
User Types	urban planners, architects, computer scientists
Interface/ MR Scene	optically tracked stylus interface, PTCU-based outdoor augmentation of urban space
Observations	stylus interface moderate, optical tracking influenced by occlusions

Figure 84: User Painting on Canvas in MR Scene

The MR equipment was installed inside the MR Tent prototype for the first time to test the spacial interface layout of ColorTable and Urban Sketcher. The optical tracking was a little bit better due to the controlled lighting situation, but still suffered from occlusions caused by the user working near the screen. Sketching and painting on 3D objects and canvas layers in the MR scene enabled the user to intuitively modify their texture directly with the active tool (Figure 84). The wireless button event was improved by stabilizing the radio transmission, now allowing moderate but fluent painting and sketching.

5.4.13 Cergy-Pontoise Scenario

Event Type	Outdoor MR Tent Workshop
Date	10. September 2008
Location	Caserne Bossut, Pontoise, France
Participants	43 + 15 IPCity
User Types	urban planners, architects, inhabitant representatives, commerce and industry representatives, city authorities, computer scientists
Interface/ MR Scene	laser pointer stylus interface, PTCU-based outdoor augmentation of urban space
Observations	live video scout needs reliant wireless connection and automatic stream reconnection and higher bandwidth >100Mbit and an interface for MR scene integration and calibration, standalone painting performance moderate, performance of integrated applications far too low (< 1fps),

Figure 85: MR Tent on Site in Real Urban Planning Scenario

The first workshop with the specifically designed MR Tent (see section *3.2 MR Tent*) was located on the premisses of the old Bossut barracks right in between the two towns Cergy and Pontoise. This location was chosen because the whole area will be reconstructed to form a new urban center connecting the two towns. The tent was set up exactly on the axis between the two current town centers Figure 85.

The integration of the ColorTable [96] as a component (*4.2.4.1 ColorTable Nodes Component*) in Urban Sketcher made the relevant nodes for rendering the input from the ColorTable interfaces avail-

Figure 86: User Moving Tangible Object

able in the application. For integrating interactions performed on the tangible table, Urban Sketcher was adapted in a way that tangible objects on the table could be used to position and orient media content created with Urban Sketcher (see *4.2.4.2 Tangibles*). The full integration of ColorTables node structure into the scene graph of Urban Sketcher resulted a rendering frame rate below 1 fps, thus far below real-time requirements needed for live augmentation and sketching. Too many implementation issues regarding the performance of the newly integrated nodes led to the idea for another integration approach based on one slow and one fast rendering cycle.

All workshop sessions were moderated by one of the urban specialists, who had the laser pointer available for pointing onto real and virtual objects in the MR Tent. In Figure 86, a user interacts at the table, while the result of his action is observed on the screen by the

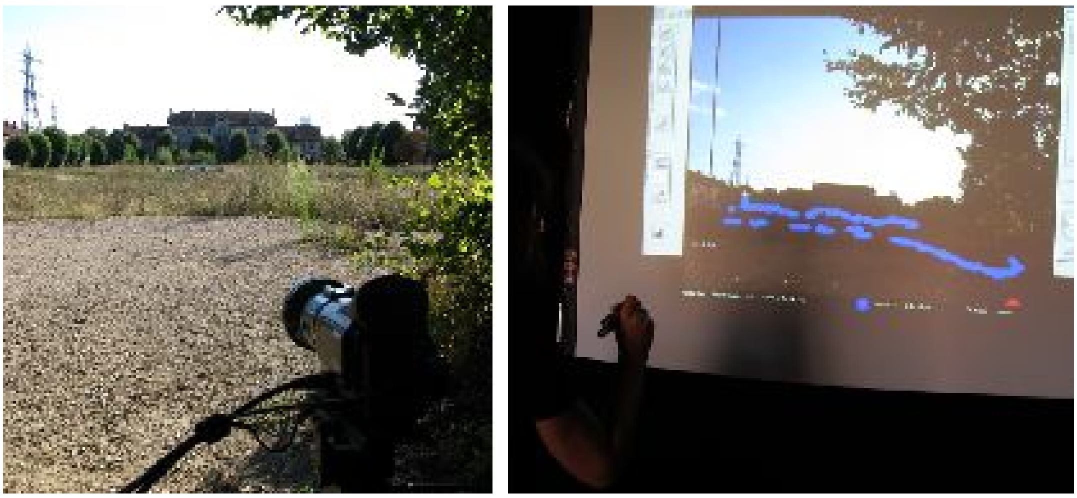

Figure 87: Video Augmented Painting and Sketching on Site

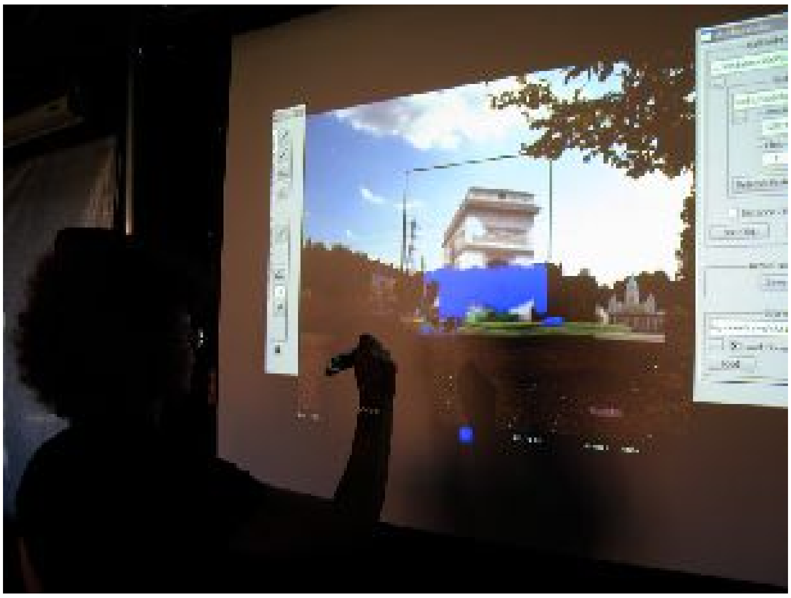

Figure 88: Architect Experiencing the Laser Pointer Interface

other people in the tent. In Figure 87, the setup of the PTCU for the live augmentation of the building site inside the tent is depicted. The right image shows sketching in the live view of the MR scene. The laser pointer interface was found to work almost seamlessly, but not fast enough as urban planners are used to creating quick sketches (Figure 88). The sketching is part of the natural negotiation workflow of architects and urban planners and needs to be supported in a future application version working at high speed.

The scout (*3.3.5 Scout*) was extended to support GPS and orientation indexed video streaming from the vicinity of the MR Tent using a 100Mbit WLAN Router. The stream was displayed on the screen inside the tent, but was not fully integrated and calibrated with the MR scene and Urban Sketcher. The wireless connection was unstable as the scout moved further than 10m from the tent and the automatic reconnection did not work as expected. Another issue was the unstable bandwidth limiting fluency and resolution of the stream.

5.4.14 HIT Lab NZ

Event Type	Indoor Open House
Date	10. October 2008
Location	HitLab, Christchurch, New Zealand
Participants	120
User Types	AR and MR students, citizens, computer scientists
Interface/ MR Scene	laser pointer input, new design of 2D screen aligned tool menu, back-projected MR scene, ARToolkitPlus marker-based miniature MR scene tracking
Observations	painting performance moderate, well received by users

Figure 89: Back-projected Interaction Screen

At the open house event, an augmented map of the city center of Christchurch was back projected on the interaction screen (Figure 89), thus avoiding shadows of the user on the screen. For tracking the interactive viewport with a video camera, the map contained fiducial markers. Laser pointer input allowed users to manipulate the MR scene.

Audio feedback was considered to be useful at some point and as a result integrated, so all painting, sketching and locating activities in the MR scene were each reflected with specifically designed

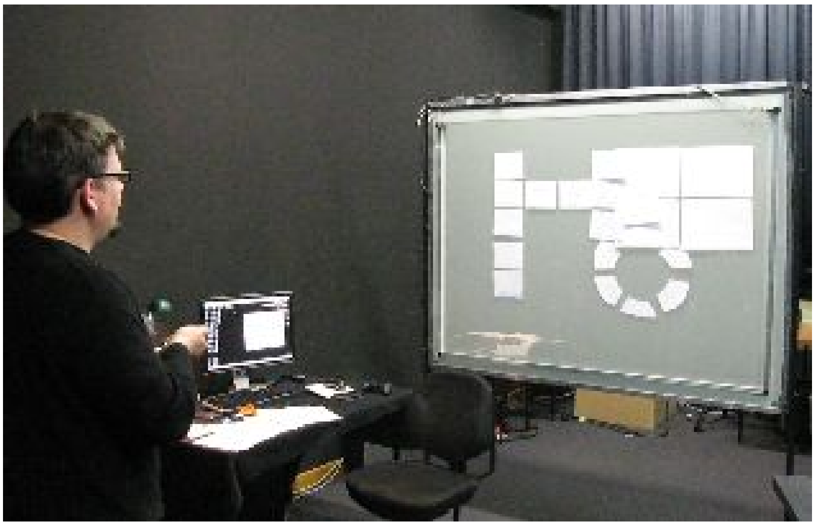

Figure 90: 2D Overlay Menu Development

sounds. User acceptance varied to some extent, as some people felt distracted by the "*noise*", it was considered to redesign the sounds, so direct inter-human communication is not influenced too much.

Figure 90 reports on a menu design phase conducted at HitLabNZ. Different menu layout sizes and designs were tried out by interface design professionals for effectiveness and accessibility when interacting close and from some distance to the screen with a laser pointer. Placing the tools menu next to the perspective view, as previously done, distracts the user. The need for an efficient interface solution minimizing distraction, while still giving a maximum amount of tool choices inspired the further interface design. A multifunctional button in the top left screen corner was the design choice for activating the overlay interface menu. The round button icon indicates the currently active tool and its background color provides feedback of the currently chosen painting and sketching color. Touching the icon with the pointer activates the overlay menu, offering several tools for MR scene manipulations. The most frequently used MR tools from Urban Sketcher were moved to the newly designed 2D overlay menu, described in detail in section *4.3.1 Screen-aligned Interface*. Once a selection is made, the menu is either hidden and the respective tool activated or a dialog requests additional user input. The expert menu is only visible when the upper right display corner is clicked, thus avoiding display clutter.

5.4.15 European City of Science Exhibition

Event Type	Indoor MR Tent Workshop
Date	14. November 2008
Location	Grand Palais, Paris, France
Participants	1000nds + 15 IPCity
User Types	citizens, children, urban planners, architects, computer scientists
Interface/ MR Scene	laser pointer stylus input, PTCU-based indoor augmentation of exhibition
Observations	positive user feedback on laser pointer interaction and 2D menu interface, performance of on-screen painting moderate

Figure 91: MR Tent at Science Exhibition

A very large audience was present at the European City of Sciences exhibition at the Grand Palais in Paris. The MR Tent was set up inside the huge exhibition hall, and the PTCU was placed just next to the side entrance (Figure 91 left), so it could be controlled to overview and augment a crossroad filled with streams of visitors Figure 92. The event was open to the public all day until late evening and always flooded with people, who stepped inside the tent to try out the MR interfaces (Figure 91 right).

A large number of people played with Urban Sketchers interfaces, often placing and painting canvases near the crossroad, in the middle of people walking by (Figure 92, Figure 94). It was observed that the 2D overlay menu for the screen proved to support fluent in-


Figure 92: Augmented Exhibition

teraction and good affordance of the deployed icons. The very dynamic MR scene inspired creativity of users, who had a lot of fun and sometimes simultaneously engaged in altering viewing direction and changing the MR scene (Figure 93).

It was obvious to the observer that people intuitively learned to use the interface, sometimes requiring a brief explanation on how they can achieve a desired result or where a tool or the menu can be activated. Selecting and inserting content from a standard file dialog was difficult, as its design with standard widgets is not optimized

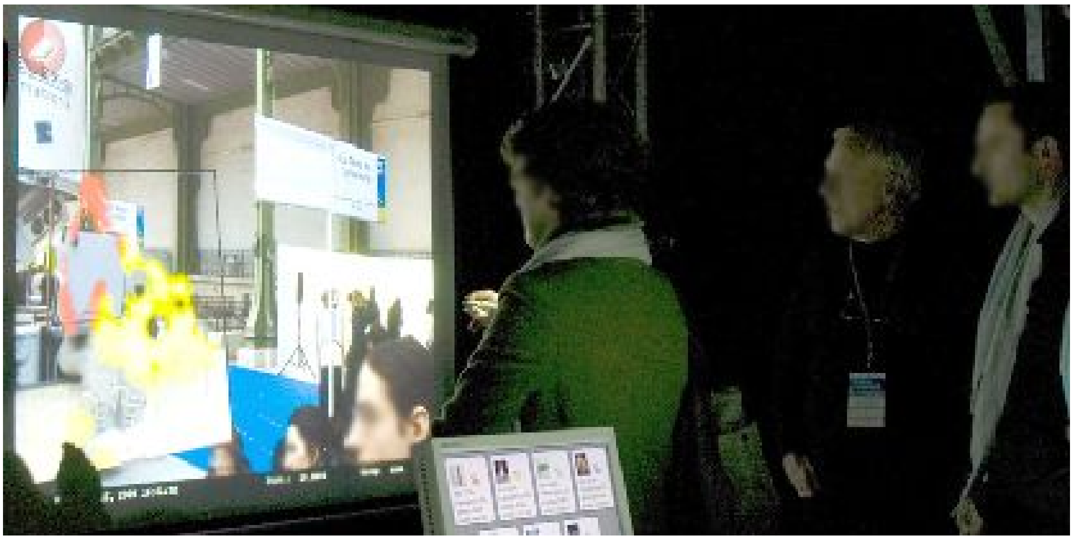
Figure 94: Painting the Augmented Space

Figure 93: Simultaneous Engaged Exhibition Visitors

for laser pointer interaction. Most people chose to interact from 1-2m distance from the screen, reducing shadows and giving them a better overview of the displayed information. Old and young people engaged in experiencing MR and expressed themselves. In Figure 95, kids took just a minute to start enjoying MR.

The voluntary engagement of several, also very young, people using and playing with the interface indicates that significant progress has been made towards a natural designed, easy interface for intuitive individual expression.

Figure 95: Kids Experiencing the Sketching Interface

5.4.16 Pontoise Scenario

Event Type	Outdoor MR Tent Workshop
Date	14. June 2009
Location	Pontoise Park, Pontoise, France
Participants	25 + 15 IPCity
User Types	urban planners, architects, residents, city officials, artist, computer scientists
Interface/ MR Scene	laser pointer for on-screen input, PTCU-based outdoor augmentation of urban space
Observations	scout needs feedback from inside the tent, performance of on-screen painting moderate

Figure 96: MR Tent on Site in Pontoise

The Pontoise workshop took place in a park with a football field not far from the town center (Figure 96). A public building for the center of commerce, right next to the park, as well as the surrounding is to be revamped. The workshop was orchestrated by urban planning professionals who invited architects, citizens, town administration officials and an artist to collaboratively develop a joint vision of the reconstruction site, as expectations, opinions and viewpoints diverge. The tangible color table was used to design the layout of new roads, arrange interactive spatial sound supported by Gammon[43] and insert specifically prepared content in the MR scene (Figure 97).

43 http://www.eigentone.com/ (08.10.2010)

Figure 97: Discussing Around the Tangible Table

An experienced user was instructed to create a housing block with the 3D construction tool right next to the rounded car park depicted in Figure 98. The exact location was collaboratively negotiated in a few iterations of trial and error by testing and discussing possible locations. The initial texture of the block was unacceptable and changed to a simple blue tone preferred by a majority of the representatives in the tent.

In Figure 99, an artist is painting on a transparent canvas layer in front of a bridge located on the far side of the park, thereby expressing his vision of improving the integration of this concrete construction into the landscape.

Figure 98: Constructed 3D Housing Block

Figure 99: Painting Artist

The performance issues encountered at the last workshop were addressed by running the ColorTable on a separate computer. To improve performance and maintain the high frame-rate required for sketching, the ColorTable renders its frames off-screen and transmits the resulting framebuffer (including depth information) over the network to the Urban Sketcher where it is merged and finally rendered to the central projection screen. The MR scene created with the ColorTable tools was integrated into Urban Sketcher using the component described in the section *4.2.4.3 Remote Scene Composing*. The display options of Urban Sketcher for working with the environment are described in section *4.2.1 MR Views of the Environ-*

Figure 100: Live Augmented Football Field

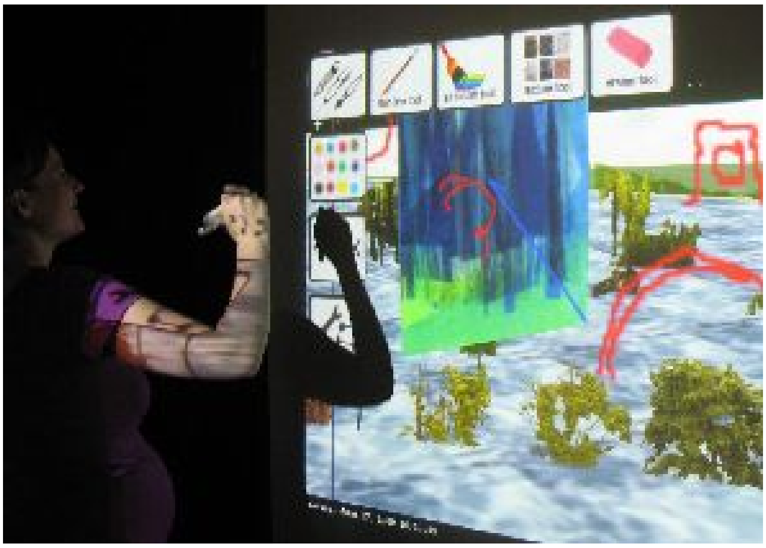

Figure 101: Interacting with the Overlay Interface

. Figure 100 shows the live augmentation of the football field in front of the MR Tent, including the composed scene from the ColorTable as well as a painted object and the 3D construction tool from Urban Sketcher. In Figure 101 the overlay menu is in use during painting and sketching operations in the composed MR scene.

Positive user feedback and fluent interaction using the interface suggests that an intuitive interface was realized, although the painting and sketching performance was not considered to be sufficient. The CPU computing power was responsible for the moderate painting and sketching speed, that is why the decision was made to im-

Figure 102: Live WLAN-based MR Scout

plement the time-critical algorithms on the graphics card, utilizing GPU parallel processing at a much higher scale than before on the CPU-based processing architecture.

The improved live video scout (*3.3.5 Scout*) was tried out using a 1Gbit WLAN router. Live augmentation of the mobile wirelessly connected media content stream was shown inside the MR Tent (Figure 102). It was found that communication support is needed for directing the scout in the environment, as shouting directions only works over short distances. A visual indicator operated from an interface inside the tent for augmenting the scout's view with instructions would be a great improvement, allowing the collaborators inside the tent to indicate directions remotely, especially when the scout is working at larger distances supported by UMTS connections.

5.4.17 IPCity Summer School

Event Type	Indoor Demonstration and User Study
Date	22. September 2009
Location	University of Technology, Vienna, Austria
Participants	30 + 10 IPCity
User Types	urban planners, architects, students, computer scientists
Interface/ MR Scene	bimanual handheld interfaces, stylus-operated semi-mobile tablet screen, natural feature-tracked textured tabletop model, interactive video augmentation
Observations	GPU-based sketching provides sufficient performance for quick sketches, user study results see chapter 6

The students of the summer school were given the opportunity to take part in a user study on bimanual interaction. The quantitative and qualitative evaluation of the setup (Figure 103) is summarized in chapter *6 Bimanual User Interface Study*. This event was very interesting, as participants, in particular ones from the Urban Renewal and Urban Issues workshops, as well as project colleagues, took part in the study, and furthermore explored additional sketching tools of the MR interface. This version of Urban Sketcher integrated the GPU-based component described in section *4.2.3 GPU Sketching*

Figure 103: Physical 3D Model with Handheld User Interface

and Painting. The MR tools support fluent and fast user input for creating architectural sketches on canvases and 3D geometries as well as geometry creation, manipulation and arrangement (Figure 105) in the space of the MR scene (Figure 104). Informative feedback from urbanists, architects and casual users confirmed that sufficient interface response time is achieved for doing quick sketches in MR, which is needed for communicating urban issues in the negotiation workflow (rendering at 30-50 fps).

Figure 104: Handheld Interaction with MR Scene

Figure 105: Selection of Colors and Media Content

The graphical interface is the same for small and big screens. For interacting, a stylus is used directly on the screen approximating the interaction metaphor to pencil and paper. The additional spatial dimension of AR and the 6DoF navigation in the MR scene let the display function like a window into space. The perspective view into the MR scene gives direct access to objects in the augmented three-dimensional space. For interaction design, 2.5D metaphors were used, imposing natural mapping on the tools. 2.5D means working in 3D while interactions mainly influence two dimensions simultaneously, *e.g.,* if the position of an object is altered in the perspective view (Figure 106), it is moved in two dimensions on the ground plane of the MR scene. Constructing 3D geometry with the 2.5D metaphor is described in section *4.3.1 Screen-aligned Interface*.

Figure 106: Using the Translation Tool

5.4.18 IPCity Final Event

Event Type	Indoor Exhibition and Demonstration
Date	24. March 2010
Location	University of Applied Arts, Vienna, Austria
Participants	20 + 10 IPCity
User Types	urban planners, architects, students, computer scientists
Interface/ MR Scene	natural feature-tracked augmented map, scout indicator, 2 simultaneous displayed MR views, augmented live stream from scout
Observations	rendering performance of quad core PC sufficient for 2 independent MR views

Figure 107: Exhibition at University of Applied Arts

Figure 107 shows the IPCity exhibition at the University of Applied Arts. For the demonstration, natural feature-based map tracking is used for 6DoF view navigation through the miniature MR scene of the exhibitions environment at the university in Vienna. Figure 108 shows the view navigation using a webcam. The interactive augmented MR scene of Urban Sketcher is displayed on the tablet screen, at the same time another augmented view can be selected for live user feedback Figure 110.

In Figure 110, a screen shot shows the real map of the university environment with an architectural map overlay including some 3D trees, cars and buildings as well as some textured canvases to enrich the scene. The little blue avatar can be moved and oriented on

Figure 108: View Navigation

the ground plane, it functions as a virtual observer (similar to the tangible view *4.2.1.2 Tangible View*). Its viewing perspective is rendered in the small window (lower right corner).

Another feature of this setup is the VPN connection via UMTS to the Scout (*3.3.5 Scout*) for streaming live video imagery of the environment to Urban Sketcher, where the stream is augmented with the MR scene created on the augmented map. In Figure 109 the mobile hardware for the scout is shown.

Figure 109: Scout Equipment

Figure 110: Augmented Miniature Scene and Virtual Viewport

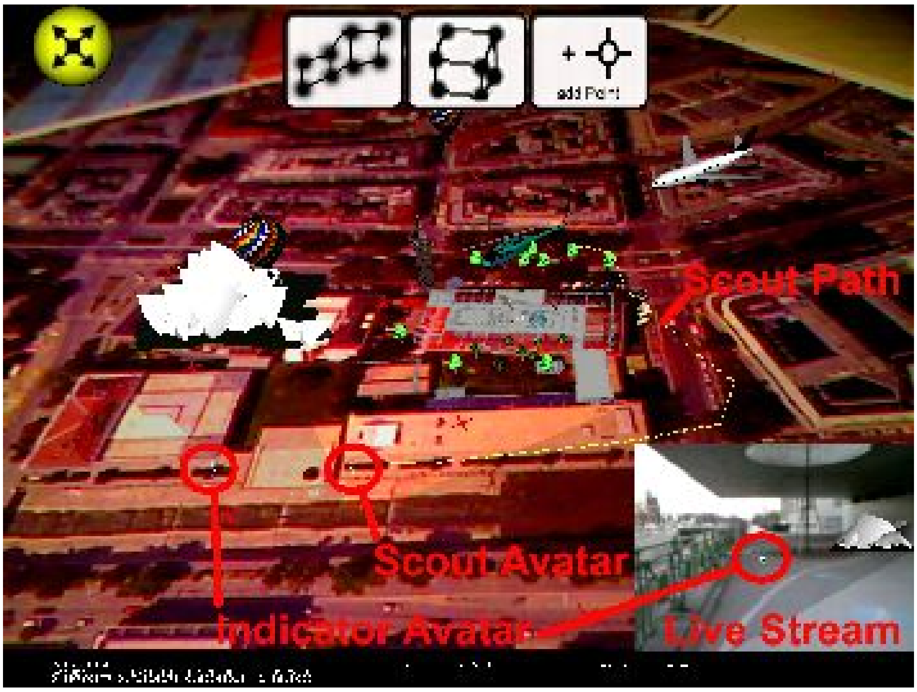

Figure 111: Interactive Scene with Augmented Live Stream

For communicating with the scout, text chatting is used in combination with an avatar to indicate locations in the environment. The indicator avatar is placed using the MR scene in Urban Sketcher, its position is synchronized to the scout where the indicated direction is augmented in the view of the live stream. Figure 111 shows a screenshot of the miniature scene and the augmented scout stream. The path of the scout in the environment is represented by the yellow line on the map.

5.5 Urban MR Design Guidelines

The previous section summarized all major events and collected user impressions during the participatory MR interface design process of Urban Sketcher. The IPCity design guidelines are a joint effort of all the scientists involved in the project collated from a diversity of outdoor urban mixed reality applications including: urban renewal, environmental awareness, interactive city information blackboard as well as space and time augmenting urban storytelling games. What they all have in common is the engagement of people with urban issues at different levels. The consolidated IPCity guidelines are part of the conclusions summarized in deliverable 3.5 [167].

"*Designing for Mixed Reality experience in the City*" and "*Designing for enabling the user experience*" MR experience is enabled by interfaces which mix various levels of reality along the MR Continuum (Figure 1). Interface design (*2.2 Interface Design*) is influenced by numerous aspects concerning the environment, people and technology. When designing, it is recommended to consider all MR technology aspects spanning the proposed continuum in Figure 2. Furthermore influences on MR (Figure 5) are relevant for designing as they propose essential relations. Depending on the urban issues and tasks considered for the desired application, design decisions are required. In general it is helpful to follow industrial standards, use widely available hardware, calculate work needed to support multiple platforms, and use open interfaces. Opportunities for crossing MR boundaries need particular attention for mobile applications. Consider anchoring content for the MR experience in the city starting from the real environment in order to effectively combine cues. Be aware of real-life obstacles, such as traffic, temporal events and seasonal changes.

"*Designing for presence*" and "*Designing for engaging with the city*" adding aspects concerning aura and place to the concept of presence extends it to engagement. The users' sense of emotional engagement is involved, thus users who actively take part, contribute and interact "*engage*" in mixing urban realities (*2.2.1 Presence and Engagement*). Designing for perceptual immersion and sensory presence involves interfaces and events of information cues. Design ambiance of places, use multimodality and complexity, use elements of narration, story telling and drama, include material aspects and affordances, integrate time-critical tasks or competition to aid the users to engage. Design another experience and expose the users to reality.

"*Designing for collaboration*" co-presence naturally leads to collaboration (*2.2.2 Collaboration and Participation*). Provide dynamic, expressive and controversial content to challenge the users to express and share their ideas or open a debate. Design using proximity in collaborative interfaces and implement social affordances for constructive interactions. Motivate participation in achieving collective results using one workspace with managed territoriality. Establish common grounds and provide similar interface conditions for all using natural mappings.

Design influences and guidelines concerning urban MR interfaces have been mentioned and vary depending on relevant tasks for progressing on specific urban issues. This chapter on workshop experiments comprises field work in urban environments for urban planning. In the next chapter tabletop models and bimanual handheld interfaces for urban planning are examined in a user study.

Chapter 6
Bimanual User Interface Study

The Urban Sketcher has been used in the MR Tent as part of multiple workshops, and this led to a new interface idea. It was motivated by the observation that at some stages during the collaboration process in the MR Tent small groups are formed to work on, and discuss particular issues of a certain stage in the overall workflow. Results are afterwards shared with the rest of the co-workers. Another situation in which the proposed interface could prove useful, is a less complex setup than in the MR Tent, when working with tabletop models of the reconstruction site. This is common practice to transpose an architectural scene from an on-site situation to a studio setting utilizing a tabletop architectural model, while also moving the interface closer to the users. The intention of this setup and the following experiment was to specifically investigate view navigation and simultaneous interaction in the MR scene, which was only informally evaluated in previous experiments in the MR Tent. Results of this user study were partly published in the paper on “Bimanual Handheld Mixed Reality Interfaces for Urban Planning” [152].

6.1 Overview

As a meaningful study setup, a table with a flat map and an architectural scale model consisting of block-shaped houses (Figure 112) is used. The map and the buildings are tracked with a natural feature tracker, using a handheld web camera. The partly textured house models partially occlude the map, but the tracking still works in most cases. The scene is presented in a video see-through AR mode on a tablet screen with stylus input. Exploring and working on the augmented tabletop model requires navigation with the webcam to choose desired perspectives and details. These viewport adjustments are elementary for interaction tasks in many use cases and direct the area of attention.

In contrast to traditional software tools in VR setups, where constraints simplify navigation (*2.2.3.1 View Manipulation*) and reduce the mental load, the degrees of freedom are not reduced, thereby keeping the immediacy of interaction. The aim is rather to support the user by adding real-time visual information relevant for the perceptual motor loop [36] and by combining naturally occurring 2D and 3D interaction, keeping the mental load at an acceptable level.

Two camera navigation techniques were designed for comparison in the scenario, one similar to the viewfinder of a photo camera and the other similar to an "*eyeball in hand*" [172], often used in practice by MR experts but hardly mentioned explicitly (Figure 113). Guided by related work, especially by Balakrishnan and Kurten-

Figure 112: Bimanual MR Scene Manipulation

bach [9] who found that "*operating camera control in the non-dominant hand is beneficial*" interface decisions were made. Also the preferences of creative people for interfaces that "*feel right*" were taken into account [9], as well as previous workshop experiences, observations and discussions.

A bimanual operation for simultaneous view navigation and manipulation tasks is used in the experiments setting. Two promising bimanual interface configurations were chosen as the main conditions:

- A fixed camera rigidly attached to the display, which can be moved together with the display in order to adjust the view into the mixed reality scene (Figure 112).
- A free camera (with a small tripod attached for convenience), which can be moved around the mixed reality model with one hand, while the display is stationary (Figure 113).

In each case, operation is bimanual: One hand manipulates the viewpoint, while the other hand interacts with the touch screen using the stylus. Subjects performed three elementary tasks – searching, inserting and creating content. These are commonly found in, but not limited to, urban planning scenarios when working with MR scenes. In order to characterize both interface device configurations mainly task completion times, mental load, physical load, user role

Figure 113: Bimanual Interface Operation

and user ratings are investigated. Accuracy and error rate were not considered to play an important role in this application scenario and were therefore not measured explicitly, but are reflected by the user performance question.

In summary, the results should serve interface designers and assist them with design decisions, ultimately guiding their intuition for creating effective communication support. Evaluation is done in a quantitative and qualitative manner using measurements, questionnaires and video observation, to find out which type of mixed reality view navigation is suitable for a specific type of task when working with tracked tabletop models.

Aiming at optimizing the interface performance the following research questions were formulated :

- Which viewport navigation will be preferred for each of the three different tasks?
- Does the type of viewport navigation speed up the task completion time for the tasks?
- How do the viewport configurations affect mental and physical load?
- What effects occur if the role of the user is considered when she is engaged using the interfaces for standard MR tasks in urban planning ?

6.2 Participants

Concentrating on a specifically designed, imaginary planning scenario with standard tasks, users with a wide range of backgrounds and varying computer experience are selected to represent real-world negotiation and planning situations. The rationale for our design choices was guided by insights from previous conducted scenario based urban planning workshops. All the subjects perform three different tasks for each of the two view navigation configurations. A selected subject group of 31 people (19f/12m) aged from 15 to 47 (*Mean*=28.97, *Standard Deviation*=6.12), includes urban planning professionals, architects and citizens with varying backgrounds and expertise. All participants in the experiment had normal or corrected-to-normal vision. One person was considered as outlier during data analysis, leaving 30 participants in the experiment. The subjects were divided into two classes, urbanists and citizens, of 15 subjects each, based on their role in the urban planning process.

6.3 Apparatus

The hardware setup adopted in the experiment consists of a 2.6GHz quad core PC and a semi-mobile pen touch screen with a resolution of 1280x800 and a weight of 1.75kg. A Logitech camera weighing 0.1kg provides a video stream at a resolution of 640x480 at 30Hz. The video is displayed on the screen and also used for natural feature-based tracking of the viewing perspective showing the textured model, without obstructing the view with another sensor or fiducial targets. The video augmentation overlays a digital model registered in 3D on the real model in real time.

Figure 114 shows the architectural model. It is 1.08m x 0.80m and has a maximum height of 0.15m. The model is represented by phantoms (*4.2.2 Phantoms, Occlusions and Layers*) in the virtual space, so occlusions of virtual objects intersecting with the real model are handled correctly in the resulting augmented view. Model size, number and density of objects were chosen to create an ergonomic interaction space, giving some freedom for the movement of the camera.

Figure 114: Miniature Tabletop Model

6.4 Procedure

The goal of the evaluation is to clarify the research questions (*6.1 Overview*) and provide data as well as insights concerning the proposed interface and device configurations. In order to obtain meaningful observations and measurements, the experimental scenario was designed to comprise three characteristical elementary tasks, which had to be completed in both of the two view navigation configurations - a within subject design 2 (interface) x 3 (tasks). All tasks were evaluated by the user's perception as reflected in NASA's Task Load Index and the measurement of the task completion time. A post-hoc questionnaire was created to summarize the user impressions, followed by a brief interview. All together the average evaluation time per subject was 40 minutes and was considered sufficient for sustained concentration, avoiding tiring effects. After filling in a questionnaire on demographic user information, an introduction to the procedure of the experiment followed. The test subjects were asked to work at normal pace. Before each task, they were instructed specifically how to accomplish it. The author deliberately refrained from any explicit training as this would have distorted the closeness to a real-world setting. The three tasks procedures are explained in the following.

Figure 115: Browsing the MR Scene

(T1) Seven cars have to be found in the MR scene. This is a pure browsing task and requires no user input on the mobile screen apart from the view navigation (Figure 115). Once all the car locations are reported and sketched on an overview paper map by the user (using her dominant hand), the elapsed time is noted. The task was chosen because it is essential to be able to find objects in larger models and scenes.

(T2) This task requires the user to insert and position three trees at marked locations in the scene. This task represents the adding and placing of content in the scene, which is part of a common workflow, but is more complex in terms of interaction than pure browsing. It requires user input and demands bimanual interaction for working with the content. In the fixed camera configuration, the user initially needs to learn moving the screen with one hand for navigation while using the pen in the other hand.

(T3) Similar to task T2, two hands are needed to accomplish the goal to generate 3D content. For this task, the user needs to construct a fence with the 3D construction tool around the region in the MR scene marked in blue. This is the most complex task. It was chosen because it represents interactive content creation, which is essential for planning processes.

The interaction procedures for all the tasks are now described in detail. For task T1, the user simply took the device, either the camera or the camera attached to the display and hovered through the physical model, while changing viewing directions in order to find and report all the seven hidden cars.

The actions of the application for inserting and constructing content for the MR scene are shown when the user touches the round tool icon, in the top left corner of the screen, revealing an overlaid inter-

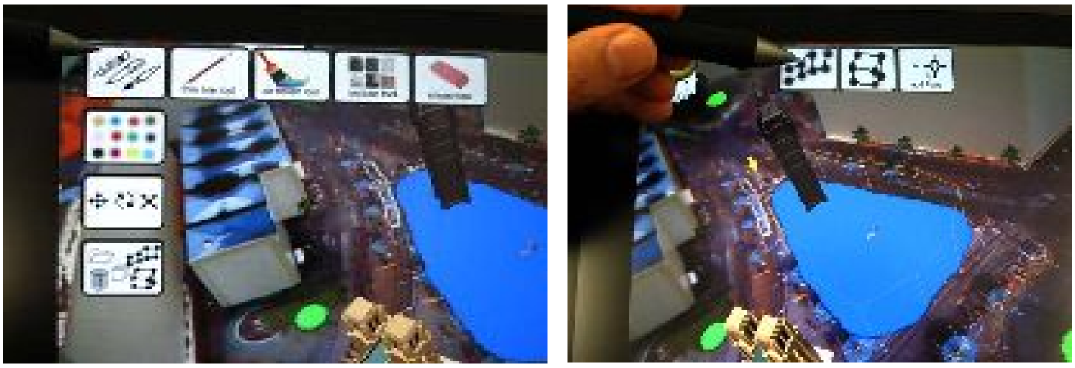

Figure 116: Pen Operated Screen Interface

Figure 117: Bimanual MR Interaction

face. This pop-up menu (Figure 116 left) gives access to common actions. For task T2, a file dialog is shown, after selecting the “load 3D object” menu item. Once a three-dimensional object, such as the tree, is selected for placement in the scene, it is loaded into the center of the MR scene. In order to move the object, the user needs to select the moving tool in the overlay menu. Once activated, an arrow icon is shown for feedback. If any object in the scene is selected, it will be enclosed by a thick bounding box for user feedback. Now this object can be moved by dragging its bounding box on the ground plane of the scene to a new location, such as one of the T2 destinations marked in green.

For the construction task T3, the user can activate the construction mode by clicking the appropriate icon in the menu. This tool allows creating a polygonal outline in the ground plane, which can be extruded with a separately adjusted height for every polygon vertex. Three extra buttons as well as a yellow arrow on the ground plane on the MR scene appear for building the three-dimensional geometry (see Figure 116 right). When indicating a position on the ground plane, the arrow moves correspondingly. The tip of the arrow indicates the position on the ground and can be used to adjust the height of a segment. With the “add point” button, the segment is added to the geometrical structure of the new object (Figure 117).

Once the user has added all points and confirmed the completion, a textured object is generated. The objective of task T3 is accomplished by surrounding the blue area on the ground plane.

The order of the three tasks and their two configurations followed a balanced Latin square distribution to reduce carry-over and learning effects among all tested subjects.

6.5 Results

Concerning the application area of urban planning, the subjects have varying experience, but also concerning previous interface experience, which was recorded with 5 variables on a 7-point Likert scale. Strong differences among subjects with little or much expertise during the execution of the experiment was observed and therefore a regression analysis for the collected data on task completion time to test for the applicability of covariates in the statistical model was performed. The result with the predictors computer experience (β=-0.73), 2D software experience (β=0.30), 3D software experience (β=-0.26), 3D interface experience (β=0.07) and virtual reality experience (β=0.05) was significant with ANOVA (p<0.05) and α=0.05 and reduced variance (R^2=0.402) by 40.2%. Now the effects on time with a 3 (Task) x 2 (Camera) repeated measures ANOVA with α=0.05 including the covariates were analyzed.

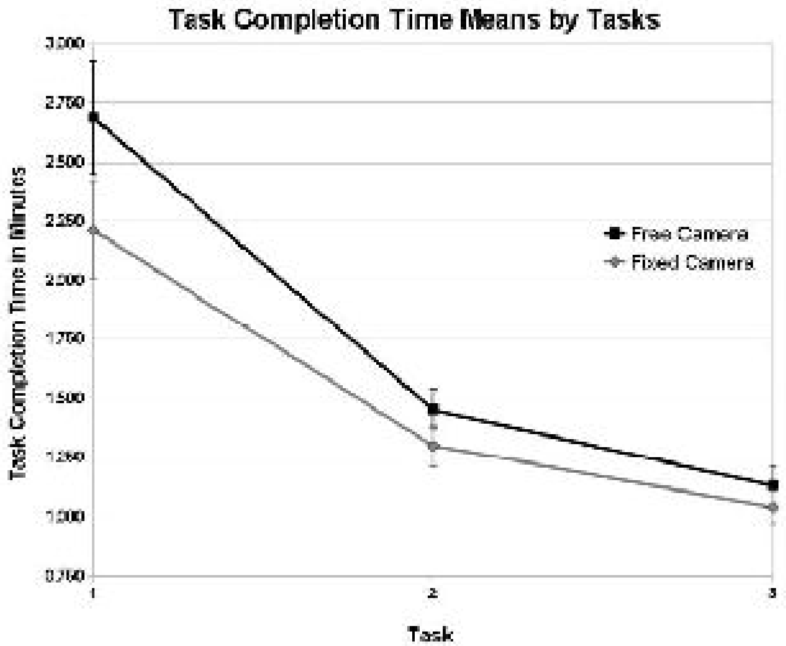

Figure 118: Task Completion Time Means by Tasks

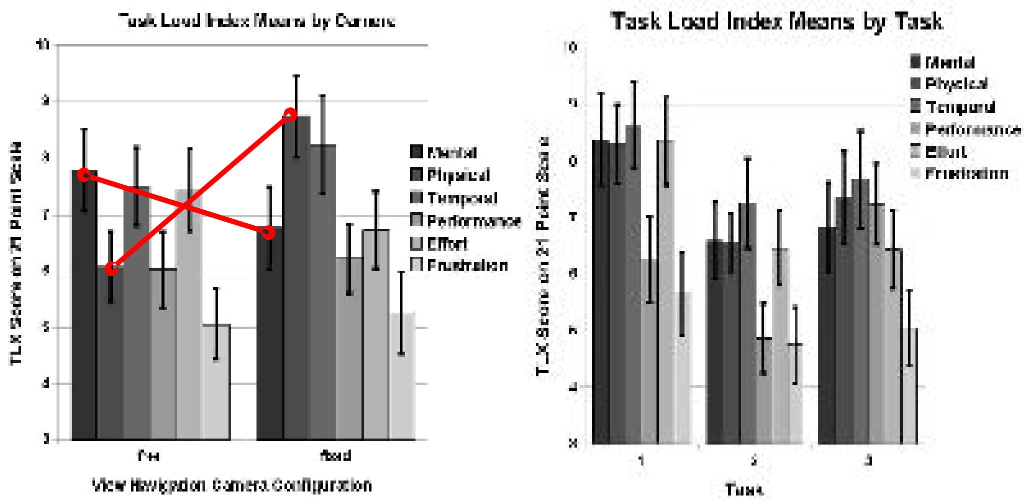

Figure 119: TLX Experiences by Camera and Task

With the covariates, the entire main effects were significant. A weak interaction between them was detected, as the lines in Figure 118 converge slightly. Looking at the camera configuration ($F1,24=5.61$, $p<0.05$), it was especially interesting to see that the free camera viewport configuration ($M=1.76$, $SE=0.10$) took more time in general than the fixed camera viewport configuration ($M=1.52$, $SE=0.09$). This means that using the fixed camera interface is significantly faster. The interaction Task x Camera ($F2,23=2.91$, $p=0.08$) is not significant. After each task, the users filled out a NASA standard TLX questionnaire reporting on her task-related impressions and experience on a 21-point scale. A 2 (Camera) x 3 (Task) x 6 (TLX) re-

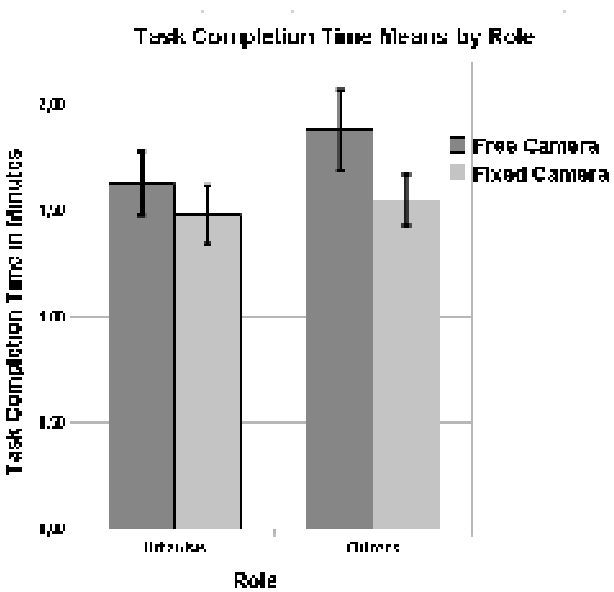

Figure 120: Task Completion Time Role x Camera

peated measures ANOVA with α=0.05 showed main effects for Task (F2,28=7.99, p<0.05) and TLX (F5,25=3.89, p<0.05) as well as an interaction of Camera x TLX (F5,25=4.47, p<0.05) (see Figure 119 left). Closer analysis of Camera x TLX showed that the mental demand (F1,29=4.09, p=0.05) lies on the borderline of significance, suggesting that the free camera viewport configuration (M=7.78, SE=0.72) has a higher mental demand on the user than the fixed camera viewport configuration (M=6.77, SE=0.73). Another effect of physical demand (F1,29=15.97, p<0.05) on the user proved to be higher for the fixed configuration (M=8.74, SE=0.73) than for the free configuration (M=6.08, SE=0.62). The potentially interesting interaction Task x TLX did not prove to show any significant relations (Figure 119 right).

Another analysis of the experiment data involved the user role in urban planning. No significant effects on task completion time were found with a 2 (Role) x 2 (Camera) repeated measures ANOVA with α=0.05 (see Figure 120). Thus urbanists and citizens perform similarly using either camera configuration.

Looking at the effects on TLX values with a 2 (Role) x 6 (TLX) repeated measures ANOVA with α=0.05 showed main effects for Role (F1,14=9.96, p<0.05) and TLX (F5,10=26.04, p<0.05) as well as an interaction of Role x TLX (F5,10=13.45, p<0.05) (see Figure 121). Significant differences were found for mental load, temporal load and effort (see Table 1). All post-hoc comparisons included Bonferroni adjustments.

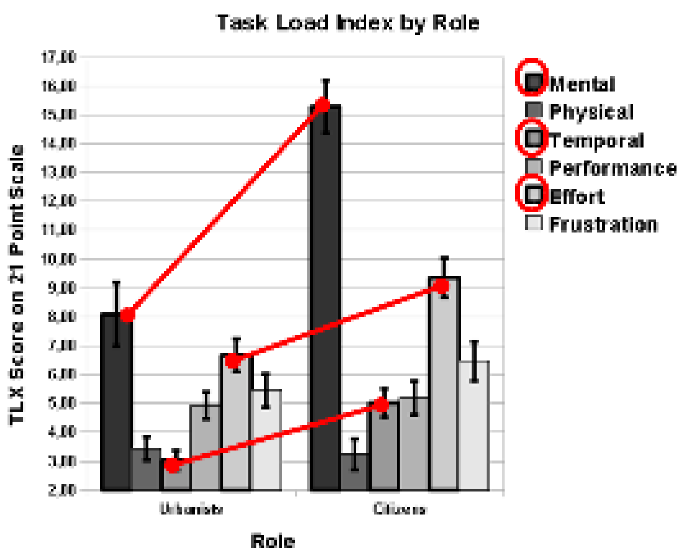

Figure 121: TLX Experiences by Urban Planning Role

		Urbanists		Citizens	
	F1,14	**M**	**SE**	**M**	**SE**
Mental Load	48.80	8.09	1.10	15.28	0.91
Temporal Load	10.88	3.04	0.34	5.02	0.50
Effort	5.09	6.67	0.82	9.36	0.91

Table 1: Significant Differences for Urbanists and Citizens

The questionnaire was filled out after all the tasks had been completed and therefore summarizes the individual insights into the experiment. The answers were reported on a 7-point psychometric Likert scale (1=disagree and 7=agree), see Table 2.

Figure 122 visualizes the significant results of the questionnaire. The results show that users had positive impressions regarding sufficient screen size and system performance, no strong tendency regarding alternative I/O devices, tracking quality was perceived as positive, but should be improved and no clear user preference regarding the choice of fixed or free interface for T1, T2, T3.

The information gained from the interviews and the observation of the subjects is summarized in the following: Almost 80% of the subjects reported that they were annoyed by the cables on camera and display, which restricted their movement to some extent.

	Mean	**SD**	**t(29)**	**p (2-tailed)**
Q1 tracking quality	4.60	1.38	2.38	<.025
Q2 improve tracking	5.40	1.48	5.19	<.025
Q3 for T1 fixed camera	4.57	2.21	1.41	.170
Q4 for T2 free camera	3.07	2.07	-2.47	<.025
Q5 for T3 fixed camera	3.50	2.15	-1.28	.212
Q6 for all free camera	3.47	1.96	-1.49	.147
Q7 system performance	5.47	1.01	7.97	<.025
Q8 screen size sufficient	6.10	1.19	9.71	<.025
Q9 different input device	3.00	2.15	-2.55	<.025
Q10 different output device	3.10	2.20	-2.24	.033

Table 2: Questionnaire Results

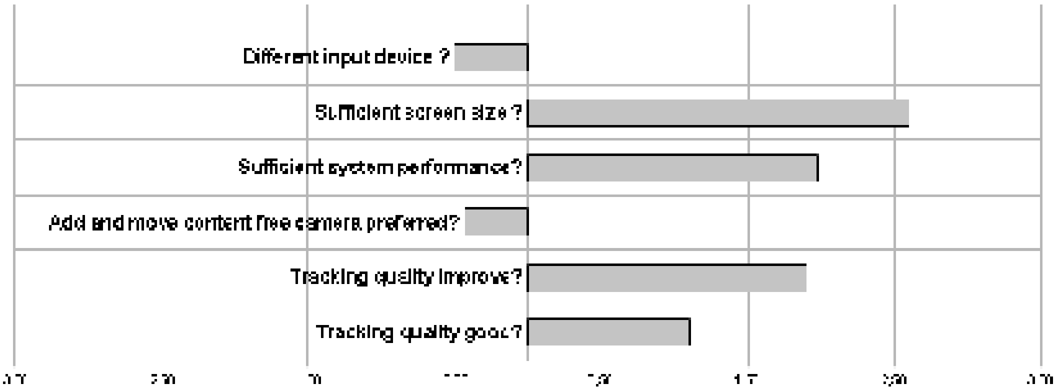

Figure 122: Graph Showing Significant Question Results

Emphasis was especially put on the camera cable limiting the free movement of the observing camera when adjusting the viewport. A wireless camera may be more suitable. The loss of tracking when rapidly moving the camera or directing it to towards mainly untextured space was another undesirable issue reported by subjects. It was obvious in the observation that all subjects had to adapt their view navigation behavior to some extent in order to obtain a continuous and smoothly displayed MR view of the scene.

In task T2, the positioning of trees, a more fluent way for activating the moving tool in order to work more efficiently was alluded 21 times. Also a bug of disappearing objects was reported. Some users with low expertise reported handling the free camera in one hand and using the pen in the other makes their view unstable, because their hand is not completely still. The resulting jitter was found annoying and sometimes even resulted in unintentional offsetting the MR view. These subjects argued that the simultaneous coordination of both hands is mentally demanding, but they still liked this interface configuration and adapted fast. In contrast, users with more expertise instantly liked this navigation method and found it intuitive.

The observation of the subjects also revealed that for the searching task, it was easier for them to navigate around the occluded objects in the scene when using the free camera in their hand since it allows easier movement at low (near horizontal) angles and in between buildings. This observation was also backed up by several statements of subjects addressing this issue. Especially for the searching task, subjects favored holding the display in their hands with the camera attached to it. They described this configuration as easy and intuitive to use in this particular interaction situation. In this context, it was suggested to mount a strap to the display so the weight is released from the hand holding it when interacting for a longer period of time. Another proposal was to optimize the display size and weight by removing the border around the screen.

Most professional subjects from the field of urban planning inquired about having some sort of top projection onto the table giving feedback from the MR scene. They also suggested an additional wall projection of the tablet view, akin to the configurations used in the MR Tent, so this setup can be better used for collaborative work.

All the user feedback concerning the setup was very positive confirming that experiencing and expressing is done naturally with enjoyment when using the bimanual MR interfaces.

6.6 Discussion

We will look at the results of this study which was designed to answer four specific research questions. In general, the influencing factors in real-world scenarios are numerous and can not all be quantified in a single statistical model. Using a single method for usability evaluation limits perspectives. For this reason a multi-method approach is used. It permits cross validation by triangulating methods and can consider complex influences like the users' internal state to obtain additional information for a more comprehensive understanding of urban MR usability issues [167].

Videotaping, observation and qualitative user feedback containing rich information on the system in general adds up to insights gained from multivariate statistical analysis of the collected data in the user study. Similar to Balakrishnan and Kurtenbach [9], it is assumed that the subjective preference data is in some ways more valuable than quantitative data. First the results are summarized and the research questions are answered followed by a discussion.

In summary, when considering previous interface experiences of the users, using the fixed camera interface is faster, the mental load lower and the physical load higher compared to using the free camera configuration. Furthermore it was found that there is no significant difference between urbanists and citizens regarding time needed for accomplishing the tasks, but a higher demand on citizens concerning mental and temporal load and effort.

The preferred condition for each of the tasks are directly addressed by questions Q3-Q5. However, only Q4 had a significant result, expressing a slight preference for the fixed camera configuration. Therefore, to our surprise there is no clear answer to the research question regarding the preferred navigation interface configuration for browsing and searching in the MR scene or constructing content. This is also evident from the lack of an overall preference in Q6. Review of the initial study questions:

- Which viewport navigation will be preferred for each of the three different tasks? - No clear user preference was found.
- Does the type of viewport navigation speed up the task completion time for the tasks? - Yes, fixed camera configuration is faster for all tasks.
- How do the viewport configurations affect mental and physical load? - For the fixed camera configuration the mental load is lower and the physical load higher compared to using the free camera configuration.
- What effects occur if the role of the user is considered when she is engaged using the interfaces for standard MR tasks in urban planning ? - Both citizens and urbanists need similar time for the tasks, but the mental and temporal demand and effort is higher for citizens.

Users judged in a positive manner about tracking quality (Q1) but thought that it should be improved (Q2) for optimal operation in interactive settings. The overall system performance was not responsible for this result and users were positive about its sufficiency (Q7). In summary the responsiveness of the application was perceived as positive with a frame rate always above 30fps. The screen size of the mobile display was experienced as sufficient (Q8). The reported "Flying away objects" were identified as a software bug and will be fixed just like the activation of the move tool will be improved so it is activated automatically once new content is loaded into the scene. In this way one user input less is needed to accomplish the same task. The open question on the demand for different input devices (Q9) was answered in the negative although some non-professional users suggested finger touch input on the mobile display and directly on the table. Professionals liked the current state with the pen as it allows preciser input. Asking about different output devices (Q10) did not give a clear answer. But many comments about future interface designs were received suggesting hybrid display configurations using the mobile display in combination with projections. The demanded wall projection of the scene is technically easy to realize and was already used in previous work with the MR Tent, but not with the interface proposed in the user study which is described in this section. The demanded projection of feedback information onto the table was also realized in previous work and will be technically challenging in combination with the natural feature tracking which is sensitive to texture and lighting changes.

Similar to the result of the study "*Exploring bimanual camera control and object manipulation in 3D graphics interfaces*" [9], using the non-dominant hand for camera control was received well by the users and seems to be intuitive in both camera configurations. The advantage of the free camera is the low weight and the higher flexibility for spatial movements needed for typical egocentric perspectives of the model, realized by navigating on street level. In general, the free camera configuration has initially a higher mental load and restricts the interaction space due to the length of the arms of the user working with a stationary display. The strength of the fixed camera setting is the low mental load and the fact that the attached display is always at a convenient distance from the user even when working with large models. On the downside, the weight of the display and the spatial flexibility are not optimal.

When working with users with varying professional backgrounds and skill levels, giving options for individually optimizing the user interface configurations in order to address a wide range of individuals sounds intriguing. However, when an interaction artifact such as the handheld MR device is frequently passed from user to user, reconfiguration is cumbersome. For example, the handheld MR device allows removing and re-attaching the camera quickly, but for user groups working on real problems, it is still not really feasible. During the MR Tent workshops it was found that workflow and natural communication are too much disrupted when the interface itself needs attention. However, when one device per user can be deployed, a certain amount of startup customization (such as taking on or off the camera based on personal preferences) may be acceptable. If the interface configuration cannot be deferred to the users, the designer must pick the right type of interface. This can depend on external factors such as the level of detail, the elevation and size of the physical models, or the number and agility of the users involved.

The interfaces support users in a wide range of expertise, independent of their role in urban planning as they need similar time for accomplishing basic tasks using the proposed interfaces. Citizens, however, need more effort and the mental and temporal demand on them is higher. This needs to be considered when using the MR tools in real-world negotiation situations. Independent of the users' expertise, all tasks were solved after a brief introduction and intentionally without any additional training. Input using the bimanual interface combined with real-time visual feedback seems to be easily learned. In conclusion, overall the user interfaces support efficient navigation and manipulation in 3D, which is necessary to complete the tasks in either of the two configurations.

This study was designed for general urban planning scenarios with typical tasks. Diversity of possible scenarios in planning phases is rich and therefore emphasis on various requirements can differ to some extent, thus limiting the findings of this study to serve as inspiration for new designs aimed at addressing more specific issues. Although the user study concentrated on urban planning, the proposed bimanual user interface configurations might be useful for other tasks in general due to easy learning and good user acceptance. Another field of application for the suggested interfaces might be the bimanual 3D object inspection part of related work on *2.2.3.1 View Manipulation*. Imagine adding more natural real-world qualities for users viewing and interacting with models of *e.g.* product prototypes where they bimanually design or operate functions.

To gain more statistically significant answers, the author is convinced that simple questions need to be asked in the context of an even more limited experimental setting in order to reduce random noise in the data. This can be cumbersome when aiming at settings for real-world applications usually involving a high amount of influential factors. Finding efficient methods to address this problem is a challenge, especially when coupled with the demand for intuitive interaction techniques.

Chapter 7
Discussion

The final discussion chapter reviews the initial research questions and summarizes research experiences made during events, workshops (*5.4 Participatory Events and User Contact*) and the user study (*6 Bimanual User Interface Study*). Conclusions on the work done are stated in the respective section *7.3 Conclusion* and issues regarding further MR development for mixing urban realities are outlined in section *7.4 Future Work*.

7.1 Mixing Realities Workspace

Collaborative workspaces created by MR communication tools often introduce seams and discontinuities which were defined as spatial, temporal or functional constraints. Seams in MR interfaces change the nature of collaborators' communication behavior. For instance, remote collaboration mediated by video streams introduces asymmetries into social interaction and is not as rich and effective as face-to-face collaboration [59]. Thus, effective communication is embodied live communication, eye-to-eye, the most intuitive and unconstrained form of social interaction, as supported by the MR Tent environment (*3.2 MR Tent*). This situation can be enhanced by digital space mediated by intuitive computer interfaces leading to mixing realities processes, thus providing communication aid by utilizing MR technology (*3.3 MR Technology*). The MR Tent provides a space for 'mixing realities' that can be viewed and evaluated together [100].

The MR scene leverages communication and serves by mediation and narration between three main families of stakeholders: decision makers, designers and non-professional end users. Each one contributes with skills and responsibility. They have different cultures, different relations to space and time, but also a different relationship to technology. None have the capacity or the brief to replace the others, yet all are needed to work together and achieve the common goal of identifying, communicating and understanding urban issues in phases of urban planning project processes. "*Although visual material - the predominant communication medium - is a powerful tool for design-oriented actors, it involves risks of 'false' consensus within multi-actor environments integrating non design-oriented stakeholders.*" [124] Regulating mechanisms like pedagogic assistance or moderation may prevent misunderstandings by cultivating ethical responsibility for a healthy communication culture. Acting in this workspace the different types of stakeholders can individually engage to experience and express necessary information supported by MR tools.

The bandwidth of information transfer can be improved when engaging multiple senses, especially as the visual sense can be triggered to stimulate 90% of human perception. MR can help to activate potential by incorporating other senses, making information transfer bandwidth richer than usual [148]. A continuum spanning MR technology aspects was outlined in *1.2 Mixed Reality Used for Mixing Realities* and influences on MR (Figure 5) serve for orientation during the development of MR. MR has the capacity to offer interactive and easily accessible communication and collaboration tools to create and propose a narrating and negotiating scene in urban processes [11].

The designed workspace for mixing urban realities provides interfaces integrated by Urban Sketcher for real-time display and interaction, using the MR scene as a mediator to form a multi-actor working environment for cultivating social values and naturally enhancing communication as outlined in the next section.

7.2 MR-Enhanced Urban Communication

The initial questions are reviewed and solutions, insights and thoughts are stated, leading to issues for future work. The author always had the stated research questions in mind while progressing the scientific research project support and engineering development with Urban Sketcher.

How can concurrently developed technology probes (MR tools and interfaces) be integrated and used to enable collaborative work in a joint workspace?

Urban Sketcher integrates all MR tools of the developed technology probes used in the workshop scenarios and renders the combined MR scene to the displays, which can be configured individually as described in section *4.2.1 MR Views of the Environment*. The configurable MR research platform, Urban Sketcher, provides a flexible basis for integrating various interfaces and devices with a strong focus on bridging communication between actors engaged in mixing urban realities. It is based on an open infrastructure (*3.1 Software Infrastructure*). The explicitly developed integration solutions are described in *4.2.4 Application Integration*. A unified MR scene graph is used to render joined workspaces and receives remote interface instructions via an XML-based API user interface. The solutions provided were used for different levels of integration for applications, interfaces and devices.

Initially it was planned to call the joined application Urban Express like in the paper by Basile *et al.* [11], which reports from the first on site urban workshop in the specifically designed collaborative workspace of the MR Tent [100] (see also *5.4.16 Pontoise Scenario*). The concurrently developed technology probes were initially tightly integrated using one scene graph. Due to several practical development issues and in particular the strong performance differences and requirements regarding the technology components used, an integration approach based on *4.2.4.3 Remote Scene Composing* was realized. This solution supports the concurrent development and testing as well as slow and fast rendering speeds at the same time. This is useful for the concurrent development of technology probes aimed at integration into a joint workspace. Future development potential lies in the tight integration approach, which requires a high amount of testing and joint development time for optimizing integrated real-time interfaces for the end user in real-world scenarios.

How can sketching tools be integrated with elementary tools for mixing urban realities?

One of the key issues for integrating MR into the urban development process is the work with media content (*1.3.1 Problem Statement*). The implementation and development of natural designed sketching tools for creating, inserting and manipulating media in the MR scene continued throughout all workshop experiments (*5 Workshop Experiments*). For user input, several interfaces and devices were experimented with (see *3.3.3 Stylus / Laser Pointer Input* and *5.4.18 IPCity Final Event)*. Major sketching functionalities of integrated tools for 3D geometry generation and coloring textured 3D objects and canvases are explained in *4.3.1 Screen-aligned Interface*. The integration of *4.2.3 GPU Sketching and Painting* empowers the user to do quick sketches in the MR scene, as required by designers. In addition the sketching tools enhance moderation purposes during urban planning sessions.

The demanded sketching on architectural models could only partly be realized, as real-time interface requirements limit the number of polygons in the MR scene. This limitation is generally not considered during the architectural model design process, which is aimed at rich details and high fidelity. A solution would require better suited model preparation tools, which was considered outside of the scope of this thesis.

How can handling and creating media content in a collaborative workspace be inspired and encouraged with MR tools, to enhance individual expression?

There needs to be an opportunity to give the individual an interaction space, allowing her to express a vision in a creative way (*5.4.6 Saint Anne Wall Scenario*). Typically creative and artful expressions involve painting or sketching coarse representations of thoughts. "*Sketching brings another dynamic element into a visual scene, reinforcing the connection between real and virtual. It means connecting the imagined with what is there, anchoring it in the real scene. For example, participants sketched on a composed scene, adding a whole layer onto it, making annotations, adding an object "on the fly", and explaining some of the implications of their decisions. Working with layers and transparencies, they created spatial collages with the sketching application, thereby lending additional depth to a scene.*" [169]

Simple, open and naturally designed interfaces encourage stakeholders to participate and take action, *i.e.* both developers and users. In order to support easy handling of media, Urban Sketcher's user interface employs the file system for media exchange. In addition, media can be inserted directly into the MR scene by devices using the API and ftp upload (*4.2.4.4 User Interface API).*

Working with MR tools to manipulate and sketch in MR scenes using direct interaction through a projected 2D window to alter media content in an adjustable 3D ego-perspective of the environment facilitates the immediate individual expression. For example, it allows an artist to change the appearance of a bridge in the environment (*5.4.16 Pontoise Scenario*). Using such an interface with various available views (*4.2.1 MR Views of the Environment*) in a collaborative situation contributes WYSIWYG [56] -based direct interactions in MR. In addition, this kind of interface has its strengths in supporting representation and moderation during a urban planning session, necessary to prevent misunderstandings, which is one of the key issues in urban processes (*1.3.1 Problem Statement*).

The two proposed interfaces in the user study (*6 Bimanual User Interface Study*) can be used in scenarios with small groups interacting around a miniature tabletop model. Multiple bimanual tablet screen-based interfaces functioning as 2D windows into an augmented 3D world could be realized to propel eye-to-eye collaboration and support multiple individual or team expressions at the same time.

Observation during the workshop experiments (*5 Workshop Experiments*) showed that taking turns on exclusive interfaces in combination with parallel accessible ones can lead to group dynamics, teaching awareness to the collaborators and initiating synergy effects, encouraging engagement and inspiring individual expression.

How can communication between humans with a wide range of expertise, engaged in urban processes, be harmonized by utilizing MR technology without disregarding anyone?

Interface design has the capacity to balance different user experience levels, utilizing natural affordances to support intuition. During the exhibition at the Grand Palais in Paris, many citizens and several children played with Urban Sketchers interfaces in the MR Tent. It was found during observation that in particular children immediately liked using the laser pointer and intuitively used it to alter the MR scene (*5.4.15 European City of Science Exhibition*). Another well-received interface was the wireless joypad for changing the augmented viewing direction of the PTCU (*3.3.4 Pan-Tilt Camera Unit*).

Multiple interface affordances can inspire simultaneous interactions in close proximity within the shared information space, MR, leading to visual contacts, which can be used for negotiation. In addition, small constraints like shared displays or limited interaction spaces or devices urging users to engage in social interactions possibly lead to a more open attitude towards one another, as users have a joint experience. For example, a fixed central MR display (*3.3 MR Technology*) can present information simultaneously to all collaborators from the same point of view, establishing a common base for discussions. The Sketcher also serves as a common focus for all the participants to concentrate on the space currently being discussed [151].

In the user study (*6.5 Results*), it was shown that participants with a wide range of expertise divided into two groups of citizens and urbanists, were not significantly different regarding the time needed for performing three standard tasks in the context of creating an urban MR scene. The demands concerning mental and temporal load and effort were found to be higher citizens, thus requiring some more patience and support for concentration in the overall mixing urban realities process. Pedagogic assistance and moderation are mechanisms with the potential to make stakeholders aware of these issues and can assist in applying and building social values for implementing a pleasant and efficient communication atmosphere for wider participation.

As a result communication among users with a wide range of expertise can be harmonized with well-designed interface affordances.

How can MR mediate mutual understanding leading to consent?

A constant loop of experiencing, expression and refinement is already common in the urban planning workflow [11]. An interaction space inside the MR Tent [100] designed for collaboration enhances this process of mixing urban realities using MR technology. The shared mixed space, MR, is collaboratively filled and designed by inserting and altering content without disregarding any actor. With this practice all issues can be communicated and individual problems can be reflected and discussed. Diverging views or controversial aspects can be modeled explicitly using "*boundary objects*" [161], represented by media content, flexible enough for further refinement by, *e.g.,* moving, painting or sketching with MR tools. Those tools serve the actors as communication bridges [124]. The self expression and joint analysis within an environment designed to support and develop social values mediates the situation with all its facets. This common activity facilitates a self-reflective process, which can influence personal positions and open up new views. The negotiation state is reflected by the instrumental MR, which gradually develops as the interaction and communication loop progresses "*… urban planners and representatives from the city … came to the conclusion that the workshop … created valuable input for further planning sessions*" [168]. Constituting a common language by mutually understanding the digital space which contains all the issues which are being collaboratively refined in several negotiation stages, is a significant step towards consent, possibly leading to concerted visions of the future.

How can MR aid decision-making in urban processes?

Urban projects function as negotiation object and negotiation medium throughout the decision-making process [124]. The activation of additional senses by using MR tools to mediate ideas leverages multi-sensory perception of all engaged urban workshop participants, who actively develop the shared communication space represented by the persistent MR scene. Natural affordances of MR tools help individuals to express their vision and require decisions during the development of boundary objects. The refinement process of the boundary objects shapes and mediates a basis for joint decisions which have influences on a larger scale regarding urban issues. "*The MR technologies developed by the IPCity team enables stakeholders to communicate using a multi-sensorial language where visual content plays an important role along with other senses…*" [11] As a result, the multi-actor decision making process is enhanced, using MR as a negotiation and documentation instrument aiding decision-making in urban processes.

7.3 Conclusion

In this thesis, an open MR Framework was presented, used for development of the MR application Urban Sketcher. Several user-centered participatory events as well as a specific user study, were used to evaluate the development stages of the MR interface realized in Urban Sketcher. The experience gained will go into the design of future interfaces, since the goal to give easy access to a wide range of expertise without disregarding anyone is still a challenge for further optimizing inter-human communication. Social values are at the center of development when engaging with mixing realities. On the one hand the values need to be considered when designing interfaces for mixing realities. On the other hand they need to be respected and further developed within the mixing realities processes.

To achieve optimal natural interface design for a specific task or application, several cycles of user-centered engagement, participation, analysis and redesign are needed, always keeping the latest available MR technology in mind. The most effective methodology for making progress was found to be based on communication, expertise, experience, intuition, observation and self-critical analysis driven by several real-world deployments of experimental MR interfaces. Making progress is not about quantity, but about quality.

The prerequisites for advancing development are multiple skills including computer programming, social abilities and management competence due to the complexity of the experimentation space. Aimed at reducing cognitive load on all acting individuals engaged in mixing realities and at harmonizing different levels of expertise, MR technology needs analysis and refinement. Hardware choices and design for physical interfaces as well as software development can solve any interface issues that occur and produce new ones. The aim to optimally support a wide range of expertise including inexperienced end users demands sophisticated software developments and interfaces, which have been deployed and tested by end users in real-world tasks. Research with close contact to end users (see *5.4 Participatory Events and User Contact*) is a challenge, as often almost final product quality is required in order to gain insights and detect unwanted seams hindering communication.

The evolving mixed reality technology is improving the rate of information exchange and quality, and users are co-operating to create multi-dimensional scenes using interactions to cross both space and time. As a result, social aspects and values are moving into the focus of research fields. A clever management of naturally occurring seams can instrumentalize them for moderation purposes and propel the cultivation of social values which aid the mixing realities process and urban projects, *e.g.,* by strengthening communities of practice (*2.2.2 Collaboration and Participation*).

Responsiveness and real-time rendering are responsible for seamless perception and need to be achieved in particular for advanced users, who are accustomed to fluent workflows and continuous responses. This applies especially when performing sketching tasks in MR.

Hard- and software components were developed and integrated by the Urban Sketcher application interface to form an interactive real-time MR environment around the specifically designed mobile laboratory MR Tent. Tools for leveraging individual expression as well as for creating, managing and playing with content were deployed to enrich communication between urban stakeholders engaged in creating and refining a shared and persistent information space. This mixing urban realities process accumulates and shares individual visions and cultivates social values, so mutual understanding and personal development lead to a basis for consent and decisions on possibly joint visions of the future.

7.4 Future Work

Future work is manifold, as several research fields are involved of relevance for future contributions to the mixing of urban realities. Many interesting questions arose during the work on this thesis. The concrete MR technology design and communication issues encountered are outlined.

Simple naturally designed interfaces can be inspiring but also need to be managed as parallel affordances, and specific tools are instrumental in urban planning processes. Moderation by professional urbanists and pedagogic assistance during joint work on urban issues contribute management aspects. Future work could further investigate common workflows in particular planning phases and extract regulating and harmonizing strategies. Natural interface design can profit from the knowledge gained and can implement regulating workflow support, *e.g.*, by scheduling the interaction access so more actors get a turn on specific tools.

The dynamic character of the communication process encountered in the MR tent can not be automated easily, but essential elements and needs can be identified and lead to new developments and interface optimization.

Support for a wide range of expertise was found in the user study (*6.5 Results*), stakeholders with different roles are not neglected when using the proposed handheld interfaces for standard tasks. In previous work by Rekimoto, handheld displays were used in "*Transvision*" for collaboration where "*... during collaboration natural mutual awareness was extensively used ...*"[141] These findings sound promising for future work, as multiple instances of the tablet-based interface from the user study could be used in a collaborative urban working scenario around an augmented miniature tabletop model. Multiple individual ego-perspectives would allow small teams or some individual users to simultaneously sketch in one MR scene with natural awareness support and make communication with eye contact possible.

Another field of application for the suggested bimanual navigation and manipulation interfaces might be the augmented bimanual 3D object inspection. Such handheld MR interfaces have a potential for applications such as product presentation or 3D industrial design.

Due to the insights of the user study, a future input and output interface device, typically a handheld touch screen, should aim at achieving a wireless high-bandwidth connection for streaming display data at a resolution of ~1280x800. The overall weight should be below 500 grams and have a run time of ~8 hours. Tablet products like iPad[44], WeTab[45], Galaxy Tab[46] *etc.* are available now. The integration of such mobile devices for direct live interaction with MR scenes will need to be explored in particular, as real-time interfaces challenge performance and battery life.

44 http://www.apple.com/ipad/specs/ (10.10.2010)

45 http://wetab.mobi/en/product-details (10.10.2010)

46 http://galaxytab.samsungmobile.com/ (10.10.2010)

Further improving the natural feature tracking quality to strengthen the natural character of the interface, relieving the user from having to adapt her behavior to fit the interface is necessary to reduce temporal and spacial seams. The stable response to quick movements in a large tracking volume would contribute a significant improvement.

Better robustness of the tracking algorithm to lighting changes and partial occlusions would also be nice to have, so the simultaneous use of tangibles on the tabletop model could be further explored. Ishi et al. [70] found that a hybrid TUI/GUI approach can avoid clutter with tangible objects on a table. Using the proposed handheld interfaces, a tangible map table setup or a 3D model with low density could benefit from a 2.5D user interface in close proximity to the tangible augmented table in a collaborative working situation.

The physical integration of projector-camera systems is a future project for the manufacturing industry. Synchronization between camera and projection resulting in two output image streams, one with the projected imagery and the other containing just the projection surface, would support various developments of vision algorithms for simultaneous tracking and projection. This setup would enable stable tracking of real-world textures while simultaneously projecting dynamic images on them, as needed when combining natural feature tracking and projections in a hybrid TUI/GUI approach for creating parallel interface affordances. The central issues in this context are rich contrast as in high dynamic range imagery and invariance to environmental light changes for work in urban scenarios.

In a future step, the proposed bimanual interfaces could be deployed in the field using the MR Tent, where a miniature tabletop model physically represents real-world constraints, *e.g.,* historic buildings as static elements of the scene, and allows to virtually model new urban structures in between.

MR technology for research is often developed to demonstrate the functionality of a certain feature or to provide proof of concept for publishing research papers. When working with real-world applications, the integration of many features and concepts is required. This leads to new issues originally not present. The most prominent one is retaining real-time capability, as timing and synchronization seams will appear in a first stage followed by interface design integration issues. Some cutting edge algorithms might address a certain problem or functionality using GPU-based implementations using, *e.g.*, Cuda[47], but need to be refined and optimized in such a way as to allow multiples of such algorithms for varying tasks to be executed in parallel. Incorporating computer vision-based real-time algorithms with fast memory exchange between them, supporting distributed MR environments, will be challenging for further enhancing and scaling MR applications with intuitive interfaces.

For example, occlusions for static and dynamic real-world objects could be computed in real-time using reconstruction algorithms, resulting in more depth cues for the augmented urban MR scene. Time-of-flight (TOF) cameras[48] could be used for depth acquisition in combination with tabletop models, but seem not suitable yet for outdoor application in large scenes. Reducing seams between real and virtual objects aids the user in perceiving depth relations and helps designers to estimate proportions needed when working with content in urban MR scenes. This would successively improve and automate the concept of using phantom canvases and 3D objects (*4.2.2 Phantoms, Occlusions and Layers*) and allow users to work in more detail.

Another computer vision-based real-time implementation could solve the tracking precision issues of the PTCU (*3.3.4 Pan-Tilt Camera Unit*). Image analysis could lead to seam-free tracking of position, orientation and zoom level of the device and contribute perfect matching of the real and virtual environment, thus optimizing augmentation quality.

MR-enhanced communication aids urban processes using the MR Tent on a local basis and involving multiple actors working collaboratively on urban issues. As the vast complexity of planning aspects involving multiple risks concerning the future of society needs to be considered by the actors involved in the urban development process, some complex issues might require even wider participation and engagement involving distributed potentials as pointed out by McGonigal[49] [106], using urban games to model and work on the problem space of real urban issues in massive collaborative environments.

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47 http://www.nvidia.com/object/cuda_home_new.html (08.10.2010)

48 http://www.mesa-imaging.ch/ (10.10.2010)

49 http://www.ted.com/talks/jane_mcgonigal_gaming_can_make_a_better_world.html (08.10.2010)

There is previous work on distributed MR systems, but issues such as massive scalability for creating, sharing and working with MR scenes ubiquitously have not yet been realized. Future work could shape, integrate and develop existing knowledge and infrastructure for engaging individuals playfully, using cutting-edge mobile hardware, soon available for end users[50], for urban development projects. A truly ubiquitous interface infrastructure without disregarding anyone is a challenge.

Future work has the potential to integrate contributions aiding mixing urban realities processes by ubiquitous cooperation, which develop and integrate technology as well as common values. Wider stakeholder participation and engagement allows those involved to develop collective consciousness about issues at stake while sharing responsibility and improving legitimacy of projects to sustainably tackle real-world problems.

50 http://www.qdevnet.com/dev/augmented-reality (08.10.2010)

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