EXECUTIVE SUMMARY

Site visits expose architecture, urban design and planning professionals to a physical context as they begin a design activity, often in search for patterns to better understand existing conditions. Current tools for understanding a site, such as photographs and maps are not sufficient to perceive and understand invisible or intangible aspects of the site in situ.

Our research agenda focused on one driving question: When visiting a site, what new tools and practices can help to visualize site conditions that are imperceptible yet critical to informed design
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decisions? Our assertion was that conventional methods to study, document and interact with a site are ill suited to capturing seen and unseen aspects that may remain hidden without enhanced aids to observation and visualization. By extension, these methods fundamentally distort the character and context of the design locus, and constrict the role that visualization can have for the duration of the design process. Given recent advancements in information visualization, mobile computing and environmental sensing, our interest was to enable a shift in site analysis practices that develop richer correlations between site, data and perception, and specifically, to induce a collective awareness and interaction with a site through spatially and temporally situated visualization tools.

Our research activities focused on a 17-acre parcel within a former industrial area of New York City known as Manhattanville, where rezoning efforts are raising questions over land use, economic development, socio-cultural diversity and environmental stewardship.

Our research endeavor was three-fold: 1] We reviewed available tools and practices used to collect, visualize and interact with dynamic hidden data about a site. We then illustrated the potential of new methods and technologies for collecting, curating and creating information as tools for site visualization; 2] We identified demographics and carbon monoxide as key datasets that frequent subjective site planning review considerations such as environmental justice, and then developed conceptual models, specific visualizations, and working prototypes with regard to Manhattanville’s complex set of concerns and 3] From what we learned, we prepared a comprehensive account of our conceptual and practical investigations, and what innovative visualization tools for site visit and site analysis as important facilitators of the design process.

INTRODUCTION

When the architect, planner or urban designer visits a site planned for design activity, what is he or she looking for? How robust are his or her tools for visualizing a range of site conditions? Now that digital, information and mobile technologies provide the necessary interface to “see” what is not easily seen, how will these impact methods of site visit, and consequently, the design process itself?

Urban planners, urban designers, and architects often visit a site prior to a design activity related to the site. These site visits are used for different purposes by different professionals, but the general goals are to get a sense for the physical site, find patterns, and discover and record new insights about the physical location and its characteristics.
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For example, an urban planner might first create a series of maps about a site that represent its demographics and use. She may then visit the physical site to view and photograph it, and look for patterns such as congregations of people, traffic flows, and vegetation. On returning to her office, she might record patterns she found onto the maps. Existing tools for this process include geographic information systems such as ArcGIS, and still and video cameras. A sample map (Fig. 1a) shows geocoded carbon monoxide data (CO) and photos provide location context.

Facing these questions, we began our inquiry with the contention that existing methods do not adequately detect nor display complex, hidden features of a site without enhanced aids to observation and visualization. By extension, these methods fundamentally distort the character and context of the design locus, and constrict the role that visualization can have for the duration of the design process. Ultimately, these forms of visualization languish as polished, static renditions of site, rather than as more robust feedback mechanisms between the act of seeing the site and the act of designing for the site.

Several issues arise in the current process. First, there may be aspects of the site that are not visually apparent while visiting the site; for example, air quality and CO levels can be important when considering development, health and environmental justice issues, but cannot be seen with the naked eye. Second, the map data and the physical site are separate, imposing additional cognitive load on the user to place data in the scene or recall the scene when looking at a map offsite. Finally, still photos and video may not represent the dynamics of the physical site and environment when trying to understand correlations or associations between the data and the site.

Our main goal was to research and develop a robust tool that facilitates the user’s ability to dynamically visualize site — to study, map, document, tag and interact with a site in multiple scales, contexts, timelines and agendas. Instead of linear and deterministic methods of visualization that convey hierarchical relationships between environment and program, client and agent, policy and form, we propose a critical review of existing tools and practices, followed by focused invention and development of new tools and practices.

Our team of researchers and practitioners in the fields of architecture, urban design, geography, planning, industrial design and computer science collectively explored and tested new practices and technologies by developing situated visualizations — dynamic visual representations that are spatially
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relevant to the place in which they are displayed — as a means of gaining insight into the notion of site and extending the role of visualization beyond initial documentation or final presentation in the design process. Our work necessarily explored techniques for directly interacting with the mixed reality, through the use of dynamic modeling, site-specific data creation, and in particular, augmented reality techniques and devices.

Our research activities were prompted by recent environmental justice questions revolving around a 17-acre industrial district of New York City known as Manhattanville, in which rezoning efforts

Figure 1. Map of Manhattanville area of West Harlem, New York City. This area comprises a 17-acre site planned for major redevelopment plans by Columbia University.
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challenged reconsiderations over land use, economic development, socio-cultural diversity and environmental stewardship. This area has also been declared the “site” for Columbia University’s campus expansion, for which preliminary design propositions have been publicized using various visualization strategies. These strategies have been publicized as “greenwashing” efforts to justify the use of eminent domain toward “public good.”

To address these issues, we introduce SiteLens (Fig. 2b–d), a prototype hand-held visualization tool to support site visits, for interacting with aspects of a physical site that do not have a natural or perceivable visual representation. Our goal is to develop a tool that helps urban planners and urban designers see new patterns and gain insight into a place by visualizing its data.

Visualizations are typically shown on a stand-alone computer display, whether as a desktop, hand-held, or head-worn device. In the figure-ground relationship, the physical environment that serves as the ground in which the visualization is presented need have no meaningful relationship to it. In contrast, we use the term situated visualization to describe a visualization that is related to and displayed in its environment; for example, a display of CO data directly overlaid on the user’s view of the physical location in which it was sampled (Fig. 2b) or demographic census data displayed in the context of the relevant city block (Fig. 2a).

Situated visualizations gain meaning through the combination of the visualization and the relationship it has to its environment. In the context of site visits, the visualizations become a virtual part of the site. Note that visualization in augmented reality (AR) is not necessarily situated visualization by our definition. However, there are several excellent examples that we discuss next.

**RELATED WORK**

We draw inspiration from several projects. Reitmayr et al. developed systems for managing and displaying large scale models and annotations in urban environments. The Vidente project has been investigating visualization of subsurface features such as pipelines and power cables for utility field workers. Their approach takes geographic data models of these subsurface features and transcodes them for visualization and filtering. In contrast, we focus on invisible aspects of a site, beyond the built environment, that may not have a natural visual or spatial representation, and on comparing multiple related datasets.

We note that sensed data has become an important topic in the HCI community as new ways of
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collecting data such as participatory sensing and mobile sensors evolve. Our work complements these systems by exploring alternative ways to visualize and interact with sensed data.

RESEARCH METHODS

Our research was conducted in four phases of inquiry and activity:

**Phase 1: We reviewed available tools and practices used to collect and visualize hidden data.**

We collected and evaluated available information about Manhattanville in order to synthesize who the players are, what the most pressing concerns and forces are, how these site characteristics are visualized, understood and measured, and why this site is appropriate for our research agenda. A brief online scan of this area’s issues quickly revealed that the most pressing concern is high asthma rates, affecting a disproportionate amount of the population residing directly next to bus depots and elevated highways (Fig. 1). The sheer proximity to these large-scale transportation systems would suggest an obvious correlation to this health crisis, and yet, the invisibility of poor air quality continues to go shockingly unnoticed. Environmental Justice advocacy groups mentioned their struggles to educate area residents who could not visualize the seriousness of the issue, or more importantly, they could not see any physical trace of this highly polluted atmosphere. Furthermore, while we found numerous anecdotal sources of information about this area, we concluded that, because the methods of collecting and producing information varied so widely, we would only focus our data sources on three key documents relating to levels of CO/particulate matter in the air:

1. **Manhattanville’s Final Environmental Impact Statement**

   On November 16, 2007, the New York City Department of City Planning, on behalf of the City Planning Commission as lead agency, issued a Notice of Completion for a Final Environmental Impact Statement (FEIS) for the proposed Manhattanville in West Harlem Rezoning and Academic Mixed-Use Development.

2. **WE ACT for Environmental Justice - 17th Anniversary Report**
   (http://www.weact.org/Portals/7/WE%20ACT%20for%20Environmental%20Justice%20-%2017th%20Anniversary%20Report.pdf)

   WE ACT for Environmental Justice (West Harlem Environmental Action, Inc.) is a non-profit,
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community-based, environmental justice organization in Manhattanville, dedicated to building community power to fight environmental racism and improve environmental health, protection and policy in communities of color. WE ACT accomplishes this mission through community organizing, education and training, advocacy and research, and public policy development. This report summarizes WE ACT's activities from 1988 through 2005.

3. Environmapper for Envirofacts Website (http://www.epa.gov/emefdata/em4ef.home)

This Web site provides access to several EPA databases to provide information about environmental activities that may affect air, water, and land anywhere in the United States. “With Envirofacts, you can learn more about these environmental activities in your area or you can generate maps of environmental information.”

Phase 2: We illustrated the potential of new methods and technologies for collecting, curating and creating information as tools for site visualization:

Data Curation

We surveyed existing tools and practices that are currently used for collecting, analyzing and visualizing air quality data, and outlining the benefits and deficiencies of each. (see Appendix I)

We analyzed and Illustrates how current site visualization and site analysis methods can limit or distort the design process in terms of client program, project feasibility, local constituencies, site physicality, environmental impact, resource management, etc.

Site-Centric Approach To Data Curation

• Eurelian World View, i.e. fixating the flows of information to the boundaries of a site
• bounded and pre-conditioned spatial context
• site analyses intended to incite intervention tactics
• site visualizations intended for representation of intervention tactics

SCENARIO: The urban designer/urban planner who is interested in studying and analyzing a specific site for its environmental conditions (usually predicated on the intention to meet minimum environmental guidelines for site plan approval, and with average access to environmental datasets such as EPA's). This user experience "begins" with an interest to align general datasets to a specific place, i.e. site-centric.

Information-Centric Approach To Data Curation
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- LaGrangian World View, i.e. following the flow of information irrespective of site
- unbounded and un-conditioned spatial context
- site analyses intended to incite changes in perception
- site visualizations intended for representation of behavioral tactics

SCENARIO: The local environmental activist who is interested in developing an environmental justice campaign that raises neighborhood awareness at the intersection of contentious dynamics, i.e. industrial/residential, infrastructural/political, environmental/cultural, agricultural/economic, etc., and not necessarily at a specific site. This user experience "begins" with an interest to overlap several datasets in order to speculate on areas of concern (information-centric).

We compared data collection methods used to produce first-person information (such as interviews, sounds, still images, video footage, observations, etc.) relative to third-person information (such as GIS, GPS, Doppler radar, remote sensing, webcam, etc.)

We retooled existing data collection methods of ethnography, geospatial analysis, informatics, and psycho-geography to take into consideration the most advanced mapping, gaming, geo-tagging, open-source and mobile computing technologies:

Site-Information Hybrid Approach To Data Curation

- Dynamic World View, i.e. mutually adaptive to both information and site considerations
- multivalent, zoomable and robust spatial context
- site analyses intended to incite changes in perception, interaction and intervention
- site visualizations intended for situated and rapidly responsive tactics for both perceptual and interventional tactics
- visualization tool and set of practices that is equally dynamic, and much more responsive in a situated visualization scenario.

SCENARIO: The local environmental activist and urban designer/planner evolve a set of participatory exchanges to develop a collective definition of environmental justice that speculates how the intersection of contentious dynamics, i.e. industrial/residential, infrastructural/political, environmental/cultural, agricultural/economic, etc., can be a set of design opportunities.
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Phase 3: We developed data curation methods relative to Manhattanville’s context

Data Collection, Method and Availability

Although we focus on visualization and interaction, data curation methods are a necessary and integral component of situated visualizations. How datasets are considered, collected and curated can impact the potential causalities of given site conditions. As part of this project, we have been collecting and curating a variety of datasets to better understand the tools for collection, aggregation, and distribution. The red dataset in Figs. 2-3 encodes CO levels we collected with a Lascar EL-USB-CO data logger and a Honeywell GyroDRM, which combines GPS with a gyro-stabilized dead reckoning module, for geocoding. Custom software combines data logs and converts the output to KML, an XML-based language schema and file format for representing geographic data, maintained by the Open Geospatial Consortium. KML is used in Google Earth and Google Maps, making it easy to import datasets from these applications into SiteLens. CO data was also obtained from EPA sites, and additional datasets have been curated from geocoded US census data and single-location environmental sensing stations. We curated the particulate matter (PM) datasets into three main areas of concern, speculating on how PM might correlate to neighborhood issues:

Health Concern

PM data as it correlates to childhood asthma might consider the following datasets:

- Age of population
- Age of residences, schools and hospitals
- Zoning
- Ambient temperature (composite of pervious/impervious surfaces and solar irradiance)
- Wind data (velocity and direction)
- Traffic patterns

Economic Concern

PM data as it correlates to property values might consider the following datasets:

- Property ownership
- Building violations
- Land use
- Median household income
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- Voting patterns
- Political/jurisdictional districts
- Tax dollars spent on public space/improvements

**Infrastructural Concern**

PM data as it correlates to energy consumption/production might consider the following datasets:

- Energy demand
- Solar shading/irradiance
- Blackout history
- Ambient temperature
- Power substation locations that use diesel to produce 24-hour emergency power
- Buildings that require 24-hour energy supply (hospitals, office buildings, police stations)
- Energy retail rates

We created 2D, 3D and 4D simulated environments related to Manhattanville with which to interact with custom data. GIS was used as a tool to interpret spatial nature of the data.

**Phase 4: We developed an innovative visualization called SiteLens**

We developed new methods and technologies that will enable hard/soft data, visible/invisible processes and actual/augmented realities about the site to be visualized.

We tested a specified set of SV that would enable the designer to reason, or go beyond the information given, about the site.

We prototyped two iterations of the system in which users interact with the data to explore visual-spatial reasoning about the site and see what works and doesn't work.
We rendered a variety of useful ways to understand the place and how it interacts with and affects flows. The following user scenario provides a description of the types of interaction and tasks SiteLens supports in its current iteration, and is followed by explanations of specific elements of our prototype:

John is an urban planner. He typically looks for patterns in a physical location when he visits a site and today is interested in environmental issues. He arrives at the corner of 133rd Street and Broadway, an area of interest for future design activities, and takes out his SiteLens. The SiteLens shows him there are several different datasets in the location, so he filters for environmental data. He sees two sets of CO data. He opens one and sees that it is displayed in the world (Fig. 2b), so he knows that it was collected at the site. He opens the next set and notices that it is displayed fixed to the screen, indicating that it was not collected nearby. He tilts the SiteLens down to get a larger scale map view (Fig. 2c) to determine where the data was captured. It is quite far away, so he tilts the SiteLens back.
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up. He freezes the scene, queries both sets for provenance and notices that someone from the community collected the first dataset and the US Environmental Protection Agency (EPA) collected the second. He wants to compare them, so he drags the EPA data to the local data to spatialize it (Fig. 2d). He makes sure that both datasets are visualized differently, and sees that there is a large difference between the EPA data and local data. He freezes the image again, captures it for later use, and walks to the next street to investigate further.

Loci of presentation

SiteLens has three primary loci of presentation: a screen-fixed display in the upper left corner, a screen-fixed, world-oriented map display, and a world-fixed augmented reality display. Our system considers the nature of the data itself and defaults to displaying it in a locus that is appropriate to the spatial nature of the data. For instance, our system defaults to display data as screen-fixed if it is beyond the current view or is not inherently spatial. In Fig. 4a, census data is relevant to the site, but is recorded on a block or superblock scale. Therefore, we present the data screen-fixed in the upper-left corner. In contrast, the locally recorded CO data is presented world-fixed because it is displayed in the locations in which it was recorded. Later, we discuss breaking these boundaries when comparing data.

Visual Representations

When mapping a non-physical characteristic such as CO level to properties of a visual mark such as the size or altitude of a sphere, we consider the representation both by itself and in the context of the physical scene. To explore different representations, we use three different visual types: spheres,
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cylinders, and smoke. These three representations were developed in collaboration with our colleagues in urban design and urban planning. We chose these generic representations as a first cut at virtual representation of physical data because dots (spheres) are familiar cartographic representations, the representations were meant to be generic to other sensor data, and the abstractions lend themselves to redundant encoding of values. In each of the representations, the visual mark is displayed in the location where the data was sensed (Fig. 4a–c). For spheres, the parts per million (ppm) value is mapped to both continuous altitude and bi-level color. Higher, red spheres have higher values, while lower, grey spheres have lower values. For cylinders, ppm is mapped to both length of the cylinder and color. Taller cylinders have higher values and color mapping is the same as spheres. For smoke, ppm is mapped to density. Denser smoke represents higher ppm values.
Figure 4. (a) Combining a screen-fixed readout (upper-left) with world-fixed data representation using spheres. Two alternative representations of the same data: (b) cylinders, and (c) smoke.
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Evaluation

As a first step in evaluating our prototype, we obtained feedback from urban designers and planners in the Columbia University Graduate School of Architecture, Planning and Preservation (GSAPP) through two iterative field studies. The studies were conducted in the Manhattanville neighborhood of New York City. In the first study, two colleagues from GSAPP explored the site using the scenario described earlier in this paper. In the second study, four participants from GSAPP used a revised prototype at the same site and were given a brief post hoc questionnaire, eliciting opinions about visual representations and system use. In both cases, researchers were present and observed subjects as they used the system. Additional unstructured discussions with subjects followed both studies.

Observations And Discussion

Moments of insight were observed. For example, map data alone could not explain why the locally recorded CO levels were higher towards the end of one street; however, visual inspection of that street during the field study revealed that, near where the higher CO levels were recorded, cars were idling as they prepared to enter the highway. This combination of virtual and physical observation provided insight into potential causality.

One frustration with the system was that the data was considered stale. This brought up two issues. First, while there was a closer spatial association between the site and sensed data, the temporal association was unclear. Second, there was a desire to have live or dynamic sensing coupled with existing data to “further explore an area or fill in the gaps.”

Representation and Presentation

Reactions to the different representations were mixed. Spheres were considered better than cylinders for localizing the data. In terms of specific data values, participants were initially confused about whether the CO ppm value was mapped to sphere size or height. Surprisingly, we found that the psychological impact of the smoke was more important than the more accurate localization and value of the other representations. One participant said “I like the smoke...It’s hard to see quantity of things, but... psychologically it helps to represent the idea better.” Another suggested that perhaps “you just need to know bigger or smaller, but not the actual value.” In further discussion, smoke with the option of visualizing spheres was suggested because the initial representation of smoke provided a stronger psychological effect, provoking stronger reactions.
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In general, we see the need to provide the user with more control over visual form (geometry, color, size) and data mapping in the spirit of Chuah et al.’s SDM. For example, while shadows were considered useful for enhancing the sense of realness and provided distance cues, our design choice for mapping CO concentration to height was not considered obvious. Participants wanted to try alternate visual representations to explore changing data perception.

In terms of presentation, a difficulty with the screen-fixed display was that, while the data was representative of the site (including census data), participants felt that it was insufficiently dynamic. One stated that the data “doesn’t change when I move around, so it feels less important.”

Interaction

In our first iteration of the system, subjects were distracted by the instability of data. Our combination of data position and sensor fusion in the second iteration significantly stabilized the visualization. While the actual placement of data was slightly less accurate, the location of data was sufficient for associating with local features of the environment.

Freezing the camera image, when desired, while keeping the overlaid graphics live, supported manipulating the interface and visualization without having to keep SiteLens pointed at the scene being overlaid. As an extension of this, we found that the on-screen user interface controls were best positioned in the lower left and lower right of the screen and along the edges where the user’s thumbs could easily access them. However, direct manipulation of the visualizations, such as touching them to show metadata, was useful once the display was frozen. Selection of specific nodes in dense areas of data was still difficult because of overlapping nodes.

Our users felt that capturing combined images of the physical and virtual scene to create a single “real” image was useful for documenting the site visit. Using the SiteLens prototype was not felt to be significantly harder than using a video or still camera and could be imagined as a common tool. It was even suggested that SiteLens could be used for an iterative process of data curation, where visualization and sensing are combined with organizational tools to help create new datasets that create a portrait of the site.

Key Findings

- Need for greater tools for data curation
- Use of tools in the moment as important as output from tool post-site visit
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- Conceptual models and ergonomics

Conclusions

Site analysis for complex environments demand equally robust platforms with which to act and make decisions in the field, and with multiple stakeholders. AR platforms offer users the means to visualize critical information that is often invisible. Social networks will not only become the future users of such platforms, they will also produce and curate the data in an open-sourced manner, democratizing the role that such datasets have in the decision-making processes of large urban projects. While SiteLens is still in its infancy, the research to development a working method that can also consider the means with which to produce and generate data became a key change-changer for the development of the unit itself.

With SiteLens, our contributions include a new application space that benefits from AR and visualization techniques, a prototype system incorporating techniques for presenting and interacting with situated visualizations, novel visualizations of CO sensor data, and discussion of early feedback from colleagues in urban design and urban planning. Based on initial usage, we plan to pursue two areas further. First, we are interested in increasing the dynamics and symmetry of sensing and visualization by extending the system to live sensor data. Second, we plan to further explore alternative visual representations for different data types.

The interim findings of this research were presented at two prestigious computer science venues, CHI 2008 and CHI 2009, with very positive feedback to develop SiteLens further.

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Appendices A-H: User Interface screenshots for SiteLens prototype
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![Image of a device displaying a screen with a menu for defining and discovering site data, including options for address, jurisdiction, concern, health, air quality, economics, and infrastructure. Another screen shows a notification for a moderately unhealthy carbon monoxide level: 6.701324 ppm, measured on 06.14.08.]
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Appendix I: Matrix of Data Visualization Approaches

**SITE-CENTRIC CONSIDERATION OF PLACE**
- Eurelian World View, i.e. focusing on the flows of information to the boundaries of a site
- Site analyses intended to incite intervention tactics
- Site visualizations intended for representation of intervention tactics

**SCENARIO:**
The urban designer/urban planner who is interested in studying and analyzing a specific site for its environmental conditions (usually predicated on the intention to meet minimum environmental guidelines for site plan approval, and with average access to environmental datasets such as EPA’s). This user experience "begins" with an interest to align general datasets to a specific place, i.e. site-centric.

**INFORMATION-CENTRIC CONSIDERATION OF PLACE**
- LaGrangian World View, i.e. following the flow of information irrespective of site
- Unbounded and un-conditioned spatial context
- Site analyses intended to incite changes in perception
- Site visualizations intended for representation of behavioral tactics

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**EXISTING APPLICABLE VISUALIZATION TOOLS AND PRACTICES**

### Site Analysis/Site Documentation For Urban Designers/Architects/Planners

Typical Climate (wind and solar) Site Analysis:
- Site analysis topics include climate, solar orientation, soil types, prevailing winds, soils, site context, visibility context, and zoning requirements.

Site Analysis:
- "The U.S. Environmental Protection Agency’s (EPA) National Exposure Research Laboratory is working with the US EPA’s Scientific Visualization Center on the Urban Microenvironments project. The project examines human exposure to environmental pollutants in urban microenvironments."  

### Typical Climatic (wind and solar) Site Analysis

EPA using “Harpoon and Epoxis” to visualize air pollutants:
- "The U.S. Environmental Protection Agency’s (EPA) National Exposure Research Laboratory is working with the US EPA’s Scientific Visualization Center on the Urban Microenvironments project. The project examines human exposure to environmental pollutants in urban microenvironments."

### AR Scouting

- "The AR scout application provides an expert mobile user interface which allows a specialist to collect various kinds of data within a virtual environment. Since the scout is connected to a network using HSDPA as GPS/RF, the data is available on-line and can be processed interactively. Therefore, a collaboration with a bigger audience can be achieved. Due to an online communication channel the audience which typically has a bird’s eye view on the exploring environment can guide the scout to desired locations. The data delivered by the scout can be of various types: images, sounds, videos. By using a sequence of 2D images even 3D models of the real environment can be captured (see interactive 3D reconstruction for details). For storing all captured data, a multimedia database is used where data is stored location-based. A vision-based localization framework allows a more precise tracking."

### Illuminating Clay

- "This interface allows users to explore and analyze free form spatial models. Using this platform we explore the domain of landscape design, where the relationship between form and computational simulations is of particular relevance."