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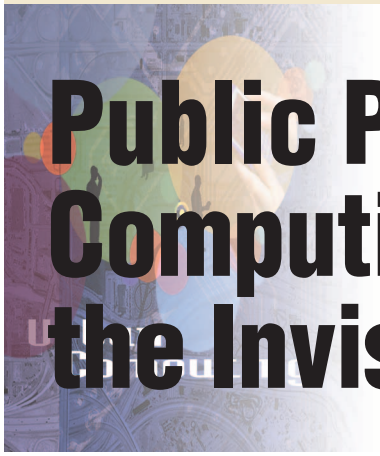
Published in:
Computer

DOI (link to publication from Publisher):
10.1109/MC.2006.323

Publication date:
2006

Document Version
Accepted author manuscript, peer reviewed version



Public Pervasive Computing: Making the Invisible Visible

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The increasing deployment of pervasive computing technologies in urban environments has inspired researchers to explore the intersections between physical, social, and digital domains. The multidisciplinary Just-for-Us project is developing a mobile Web service designed to facilitate new forms of interaction by adapting content to the user's physical and social context.

Pervasive computing technologies have radically altered how individuals relate to one another and to their environments.[1] People in urban areas routinely rely on mobile phones, including short message service texting, to communicate as well as coordinate their social activities.[2,3] Smart phones and Internet-enabled personal digital assistants (PDAs) enable users on the go to access online communities and services, as well as extend the potential of SMS through new chat and video-based capabilities.[4]

The deployment of low-cost wireless sensor networks has made it possible for mobile services to adapt content to the user's physical and social contexts. For example, some dating services alert subscribers to nearby potential partners matching their attribute pattern. In select cities, members of cafés and music clubs can swipe electronic cards at the doorways to identify the whereabouts of other members as well as to identify current hot spots. More experimental mobile services reveal the location of friends in the user's vicinity, provide context-based event and tourist information, and enable people to attach virtual text and media content to physical locations for others to find.

These trends have motivated researchers within the human-computer interaction (HCI) community as well as sociologists and city architects, planners, and designers to explore the use of pervasive computing technologies in inhabited environments.[5-7] Adding a digital layer to the existing physical and social layers could facilitate new forms of interaction that reshape urban life. While commercial information providers would create, own, and maintain this new layer, the public would greatly inform its form and content.

Initiated two years ago, e-Spective is a multidisciplinary exploration of public pervasive computing in a specific city precinct: Federation Square in Melbourne, Australia, shown in Figure 1. This popular mix of restaurants, cafes, bars, a museum, galleries, cinemas, retail shops, and open areas is centrally located on a major tram line and across from the main train station, making it an easily accessible, convenient place to gather and socialize. It is open every day of the week, from early in the morning until late at night, and serves as the focus of many civic events and activities.

Federation Square's structural fabric incorporates various public digital technologies, resulting in a unique hybrid physical-virtual space. This offered an ideal setting for studying the effect of pervasive computing and mobile communication technologies on social behavior, leading to the development of Just-for-Us, a prototype system designed to encourage new forms of interaction.

Published by the IEEE Computer Society

ARCHITECTURAL FIELD STUDY

Designing computer systems for public use differs fundamentally from designing such systems for the workplace or home. System developers and HCI designers must first obtain a fundamental understanding of a physical space and how it impacts the social interactions taking place there.

As a starting point for the e-Spective project, we examined the seminal works of urban planner Kevin Lynch and architect Christopher Alexander[8,9] that have influenced a number of HCI efforts. For example, Thomas Erickson and Wendy Kellogg[10] argue that to support communication and collaboration among large groups of people, digital systems should provide virtual "windows" that let users "see" one another. Lynch and Alexander also inspired Eric Paulos and Elizabeth Goodman to create the Jabberwocky personal mobile device to facilitate social interaction between "familiar strangers" in public places.[11]

Figure 1. Federation Square, Melbourne, Australia. Opened in 2002, the popular public gathering place offered an ideal setting for studying the effect of pervasive computing and mobile communication technologies on social behavior.

While such research has mostly adapted architectural concepts or applied an architectural methodology to computing challenges, our aim was closer to Lynch and Alexander's original purpose—analyzing and understanding a physical space, from the level of a city precinct down to each individually designed element—but in this case to inform digital rather than physical design.

Guided by their analytical techniques, we systematically mapped Federation Square's physical and informational properties. Several field visits resulted in a collection of 250 digital photos annotated with written observations of the relationship between architectural elements and the environment, as well as about interactions among people inhabiting the space. Using rapid ethnography content analysis[12] and affinity diagramming, we extracted from the photographic data and notes a concise set of descriptive features for the overall city precincts as well as specific architectural elements.

We then created a Lynchian map of Federation Square, shown in Figure 2a, with color-coded annota-

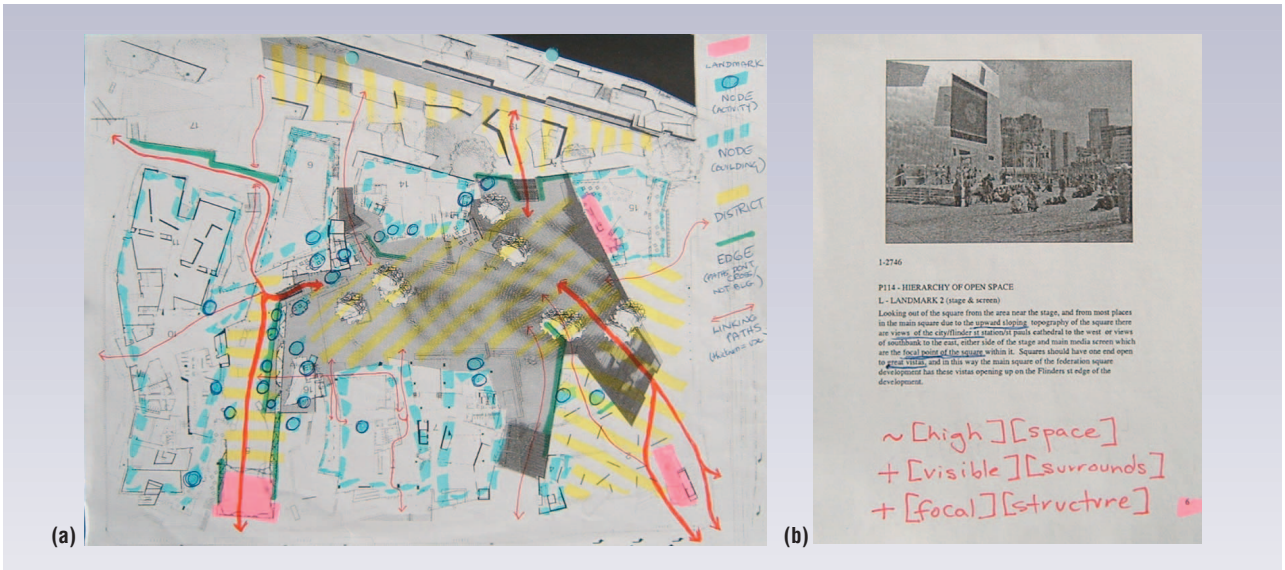

Figure 2. Architectural field study. (a) Map of Federation Square with color-coded annotations for districts, landmarks, and other large-scale features. (b) Descriptions of specific features, inspired by a pattern language approach.

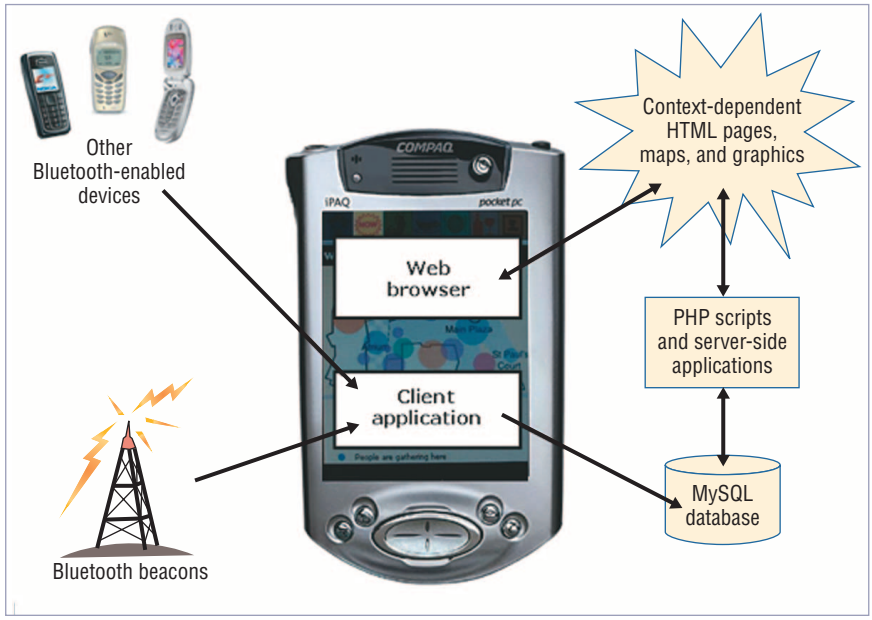

Figure 3. Just-for-Us general system architecture.

tions for districts, landmarks, and other large-scale features. This map revealed four key districts:

- a transit zone connecting Federation Square with the rest of the city;
- the main plaza—an earthy, sloping open space with a stage and media screen ringed by outdoor activities;
- a noisy, sheltered atrium constructed of machine-made materials with a huge opening toward the city; and
- a flat, damp area facing the Yarra River that is lower than the rest of the spaces.

We also matched representative photos of detailed architectural features with descriptions inspired by Alexander's pattern language approach, as Figure 2b shows. These features enable, challenge, and sometimes hinder social interaction.

Most activity occurs at the edges of Federation Square rather than in the middle. Due to its openness, however, the space has clear views of the surrounding city skyline from almost anywhere. There are many general paths and entrances, with various places designed to accommodate specific activities. However, paths between places are not inviting, and it is often unclear what is intended as a path, which path to take, or exactly where a path leads.

Locating a specific place within Federation Square can be difficult because places are often not visible from the main plaza. Also, it is difficult to identify entrances, as they are often not clearly distinguishable from the facades. The facades themselves are monolithic and do not relate to the scale of a person walking beside them. On the other hand, they constitute distinct structures in the space and act as focal points or landmarks.

SOCIOLOGICAL FIELD STUDY

Although Lynch and Alexander explicitly considered the interplay between human activities and architectural spaces, their methods revealed little about how people operate within a complex urban environment and shape their lives around public technological infrastructures.

To complement the architectural field study, we therefore studied three established social groups, each consisting of three young locals, during typical outings at Federation Square. An interviewer first talked with each group for 20 minutes about their socializing experiences and preferences and then, accompanied by a cameraman, followed the group to an area within Federation Square where they had arranged to spend some time together. Throughout the filmed visit, the group verbalized their actions as they moved around the space and responded to questions from the interviewer.

The sociological field study produced 30 pages of written notes and eight total hours of video, which we transcribed and coded using a subset of Malcolm McCullough's typology of everyday situations—namely, eating, drinking, talking, gathering, cruising, belonging, shopping, and attending.[6] Analysis of the results indicated that interactions in a city space are highly complex but generalizable.

When socializing in public, people draw extensively on cues embedded in the world around them. They use landmarks and other focal points to determine where to enter a space and which places to gather; lack of appropriate reference points can lead to uncertainty and discourage social activity. People also determine what to do or where to go by observing others and drawing on their own experience in similar public places and situations.

The presence of both friends and strangers influences social behavior. People like to "socialize by proximity"—be near others without having to interact directly with them. Setting is another important contextual factor. Individuals may choose to socialize in a place depending on the number and types of people present, its physical appearance and comfort level, activities occurring there, the location's spatial relationship to other places, and whether the space is open or sheltered.

JUST-FOR-US

These field studies generated insights that inspired us to create a computing system to facilitate new types of

social interaction in urban settings. Just-for-Us is a publicly available mobile Web service that uses a pervasive network of sensors potentially embedded in the built environment to generate a digital layer of information about people, places, and activities adapted to each user's physical and social context.

System architecture

As Figure 3 shows, we implemented Just-for-Us as an HTTP-based server-side application accessible through a mobile Web browser. The first prototype used a series of HP iPAQ h5550s connected to the Internet through a wireless local area network (WLAN) or the General Packet Radio Service.

System content is powered by a MySQL database containing maps of Federation Square (derived from the architectural field study) along with photos and descriptions of landmarks, transition points, and businesses in the precinct, including information such as spatial location, accessibility, special event schedules, and restaurant menus. The database also continuously updates participants' current whereabouts, activities, social group composition, and other contextual data and keeps a history of their interactions.

Just-for-Us dynamically delivers content to the user on the basis of database queries. The system uses PHP to generate Web pages and JavaScript to handle client-side interaction. Supporting the Web site, numerous server-side programs perform specific subtasks such as pushing information to the browser and generating maps and annotated photographs. The system uses Bluetooth beacons to approximate other users' locations—for example, in the main square or a particular cafe—and scans for other Bluetooth-enabled mobile devices to identify nearby friends.

User interface

From most points in Federation Square, the city skyline is highly visible. This informed the design of the Just-for-Us home screen, shown in Figure 4a, which presents a 360-degree panoramic view of the user's physical surroundings with annotations about buildings and places and a meter indicating the current level of social activity. In this way, the system reveals what is often invisible to the naked eye—a kind of indirect augmented reality.

When a user enters one of the square's four districts, the system pushes data about that district to the mobile device. Clicking on an annotation brings up a brief description of the landmark along with information such as events scheduled to take place there. By clicking on the arrow icons at the bottom of the screen, the user can rotate the view—which by default focuses on the district's most prominent landmark—and learn about other locations in the area. When the user enters a new district, Just-for-Us automatically pushes the corresponding view to the device.

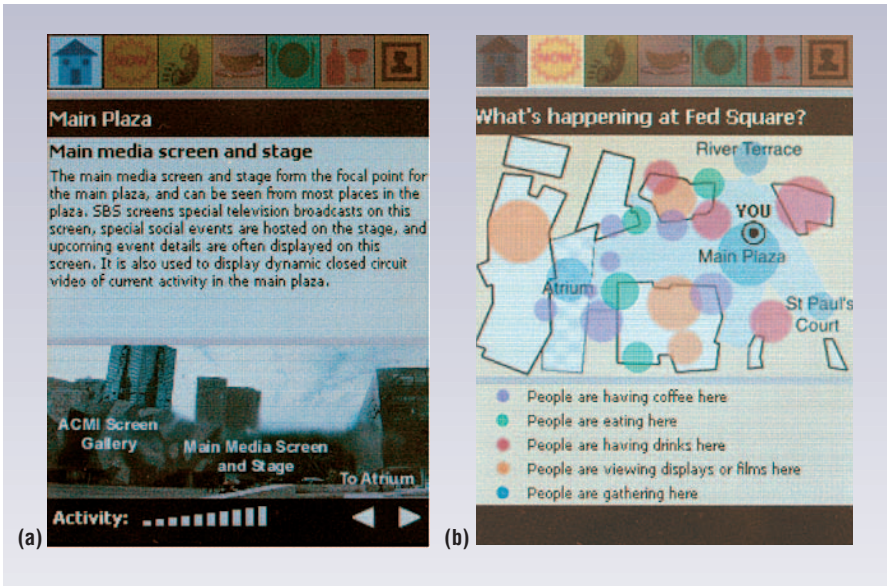

Figure 4. Just-for-Us interface. (a) The home screen displays a panoramic view of Federation Square and annotations about landmarks within the user's current district location. (b) The Now screen indicates the level and nature of social activity taking place within the user's proximity.

A key finding of our field studies—that social activity is an important cue for negotiating a physically complex space such as Federation Square—informed the design of the Now screen, shown in Figure 4b, which indicates clustering behavior within the user's current district.

Clicking on the Now icon at the top of the home screen brings up a small map showing the user's approximate location and dynamically updated colored circles. The radius of each circle signifies the number of people present, while the color represents their prevalent activity—for example, having coffee, eating, having drinks, or attending a cultural event. Clicking on a circle calls up detailed descriptions and images of the locale—for example, a particular restaurant—along with information such as wayfinding directions and menus.

USER FEEDBACK

To test Just-for-Us in real-world conditions, we had 20 socially established pairs of regular visitors to Federation Square use the system for approximately one hour. Prior to the study, we populated the database with information about their social history gathered through a questionnaire. After providing the subjects a 10-

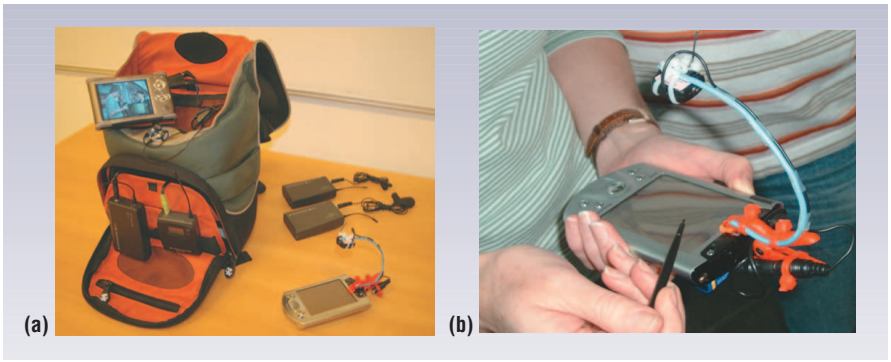

Figure 5. Data collection devices used to test prototype system. (a) Mobile field laboratory. (b) Wireless microcamera mounted on user's mobile device.

minute introduction to the system, we gave them another 5 to 10 minutes to familiarize themselves with the device interface.

Again employing rapid ethnography,[12] we prompted users to explore different parts of the system through several socialization scenarios. To foster constructive interaction, an interviewer asked the subject pairs to openly discuss their perceptions of the system during the study, interrupting them only to ask questions for clarification.

A test monitor captured these sessions using a 100-Gbyte audiovisual digital recorder in a backpack-mounted mobile field laboratory, shown in Figure 5a. A wireless microcamera attached to each user's mobile device, shown in Figure 5b, transmitted a close-up view of the screen to the test monitor, who mixed this input on the fly with the third-person view. This approach, combined with the use of directional wireless microphones, ensured both high-quality data collection and unobstructed user interaction. In addition, the test monitor entered each subject's location, as well as that of nearby strangers and friends, on a PDA.

The user study clearly demonstrated the feasibility of a public pervasive computing system such as Just-for-Us. Most subjects reported that having a digital layer of information on their mobile device that revealed hidden dimensions of Federation Square was "very cool," "useful," and "fun." They were fascinated that the system knew their current physical location, who they were with, and where other people were gathering. They also enjoyed accessing content based on public input as well as from vendors. The graphical representations of social activity led to informed discussions about what to do and where to go.

Users generally found the interface an interesting and flexible way to explore their surroundings. They found it easy to match up landmarks and the city skyline to the images on the screen as well as to reverse-match information in the system to corresponding places in the real world. On the other hand, some subjects reported that it was sometimes too difficult to see the images in bright daylight, and they suggested using line drawings rather than photographs. In addition, some formal names, such as "St. Paul's Court," were less helpful as labels than objective descriptions, such as "the black building."

Another limitation of the prototype was the accuracy of the data the system presented. Despite the design team's best efforts to input correct and up-to-date information, Just-for-Us failed to reflect some facility closures and temporary construction, confusing users and weakening the system's credibility. Further, while users understood data adapted to their physical context, they were sometimes baffled by pushed information relating to social activity that they had not explicitly asked for. For privacy reasons, the subjects generally sought to have more control over their profile so that they could review and modify what the system was making publicly available.

Based on user responses to the prototype Just-for-Us system, we are currently refining our initial design ideas to let users contribute more content in ways similar to mobile blogging, resulting in a more organic and richer public digital media overlay. We are also interested in further blurring the boundary between physical and virtual urban life by allowing users to socialize on the basis of "virtual proximity."

To give the user more flexibility and control, we are modifying the interface to more clearly indicate what Just-for-Us knows about the user's context and how the system adapts when that context changes. In addition, we are exploring ways of merging the current photographic views with interactive 2D and 3D map representations. Finally, we are extending the system to cover a much wider physical area, making the interface adaptable to even smaller mobile devices such as mobile phones, and providing omnipresent, Web-based access.

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