

Contextual awareness in mobile information processing

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Applications of mobile information technologies in architecture and building require a high degree of contextual awareness not only for localization but also for distinguishing between different types of information (relevant, redundant, stable etc.). This awareness refers to the physical context of a device, as well as to the social dynamics of the situation (including interaction with shared information). Architectural knowledge and in particular design representations support the development of contextual awareness but there are significant differences between these representations and the use of information they convey in mobile applications.

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Mobile information processing: applications, possibilities and limitations

Mobile information devices have already become not only ubiquitous but also powerful enough for information processing tasks that used to require a computer. The promise of mobility has attracted attention in design and construction. The physically distributed and socially segmented structure of architectural and building processes can profit from easily transportable, widespread and relatively low-cost means for communication and information processing. Research products include experimental and prototypical applications to building logistics, inspection and other aspects of construction management (Wang & Shih, 2002; Yabuki et al., 2002; Ibrahim et al., 2004; Lertlakhanakul et al., 2005), site measurement (Tedrumpun & Nakapan, 2004), city models (Berridge et al., 2002), registering use patterns (Nomura & Kishimoto, 2005), communicating user preferences (Shen & Teng, 2005), participation in

design and planning activities (Kaga et al., 2006), collaborative design (Bunyavipakul & Charoenslip, 2003) and teaching (Cheng & Lane-Cumming, 2003).

The encouraging results of research into architectural, design and building applications of mobile technologies do not fail to stress the significance of processing limitations of current mobile technologies. Many relate to the physical size of the devices, while others derive from the capacity of existing networking technologies. Such findings identify one of the main attractions of research into professional, demanding applications of mobile information processing: the severe practical limitations require intelligent solutions that minimize annoyance and clever choices of which information should be available at any given moment and how limited quantities of information relate to the larger databases that operate in the background. In other words, these limitations force us to focus on matters essential and central to information processing and communication rather than on compliance to indifferent standards, adher-

ence to vagues or superficial applications of powerful technologies.

Adding content and context to mobile information processing

In order to define a spectrum for mobile information processing we consider three basic applications that have already attracted some attention in research and development. The first is to provide relevant and rich yet compact information on any specific place a mobile device may happen to be. Such local information supports and influences users' actions, in particular navigation and interaction with available facilities. Mobile telephony can provide this service on the basis of cell identification and localization, while satellite navigation systems rely on databases of pre-programmed points of interest in the vicinity of the device can be presented in a relatively unobtrusive yet comprehensive manner (Abowd et al., 1997; Oppermann and Specht, 1999; Cheverst et al., 2000). Such systems may also include facilities for social interaction, such as making and sharing annotations (Burrell and Gay, 2002; Persson et al., 2002).

In architecture and building we can distinguish between two main applications in this category. The first is to provide information on buildings while the mobile device is on the outside, as in e.g. an architectural guide that suggests buildings worth visiting or a real-estate information system that informs on available property in the immediate area of the device. Such systems can be implemented on top of off-the-shelf navigation packages by entering the addresses of buildings as points of interest. Proximity of the device to the buildings would then trigger selection and notification mechanisms. However, this is not sufficient if we want the system to exhibit some degree of intelligence and adaptability to the user's implicit or explicit requirements. In both architectural guides and real-estate information systems a building's address, relative location and short textual description represent the minimal information one would expect. The points of interest should also

provide access to multimedia databases containing more information on the building, including drawings and photographs.

A second application within the same category is to provide information on the building in which the device is located. This can be an architecturally important monument or a large public building like a museum but mostly it is about facilities management, especially in complex buildings where users and occupants are not involved in the management and maintenance of the building. Facilities management in such cases operates in the background and tries to interrupt use patterns as little as possible. Registering the state of the building, diagnosing problems and communicating information requires frequent inspections, correlation of perceived and identified problems with background information, as well as combinations of short and long-term strategies. The direct availability of actual, precise, detailed and legible information during an inspection and automation of data collection are critical to the improvement of efficiency, effectiveness, completeness and reliability of facilities management.

Mobile information processing for facilities management presupposes some form of ubiquitous computing in the built environment. Any space and any building element should be capable of identifying and controlling itself, react autonomously to sensory input and above all recognize its relationship to other entities in the immediate as well as wider environment. A door, for example, is part of the elements that bound a space, a conduit between two spaces and a member of a certain class of doors in the whole building. Being able to identify the relevant clustering and inherit or propagate information accordingly would allow for a significant reduction in processing time and effort, as well as for transparent, stable definitions of entities and relationships.

A third application that partially overlaps with the previous two with respect to technical aspects concerning database structure, indexing and retrieval is design information management systems. These monitor stored information on a specific building

project and report selectively on the total state, the state of particular aspects, modifications, additions or other changes. They issue different types of warnings to the custodians of aspects, contributing designers and engineers, clients and users. The type of a warning depends on a number of variables, ranging from specialization and information ownership to personal interest and previous actions. In a mobile setting such systems operate primarily in asynchronous situations and intend to keep persons involved in a project continually up to date without overloading them with details. Nevertheless, if one expected to give feedback on the basis of mobile information devices, the information provided by the system should allow for unambiguous and comprehensive recognition of actions, problems and consequences. User feedback is expected to consist primarily of annotations and short messages.

In addition to selectivity mobile design information management is interesting because of its sensitivity to temporal and social contexts: in contrast to the previous applications, design information may change very fast and sometimes in unpredictable directions. Information that was up to date a few hours ago might be totally uninteresting –even historically– now. The social dimension is present in interpersonal relationships (e.g. directed feedback) but also in synchronous situations: in a meeting of two or more participants to a project, their corresponding mobile devices could recognize each other and provide their respective users with additional or directed information concerning the participants present, their contributions and background in the particular project. Such peer-to-peer mobile systems are becoming popular in general social interaction but have yet to find true applications in design automation.

These applications make a general-purpose technology amenable to architectural use by adding content to it – a basic method in technology transfer. As usually they can do little to compensate for the fundamental limitations of the technology like low display resolutions. On the contrary, they are

always in danger of adapting use requirements to the capabilities of the technology. The usual compensation is the promise of plasticity and efficiency, which may be inherent to digital information but can be drastically reduced by inappropriate structuring of processes and representations. Arguably more interesting are new questions that emerge in new applications. One such question is how to achieve contextual awareness.

Contextual awareness

Location and orientation

The absolute location of a mobile device can be identified with precision and accuracy by means of GPS. GPS resolution appears to be sufficient, even with respect to altitude in urban areas (Knight et al., 2006). Further improvement may be required for locations and situations where the line of site between satellite and receiver is obscured. A promising direction is the development of hybrid systems that combine GPS with wireless and mobile telephony network information. Such systems are of interest also because they use wireless landmarks like the antenna cells of the phone-network provider to approximate the location of a device. This implies a pragmatic subdivision of a physical area into partially overlapping locations, a de facto segmentation that might be acceptable for a number of applications.

Identifying the location of a device and depicting it on a map is the first step towards informing the user on his immediate context. However, it is may be insufficient as a basis for orientation. There are several cognitive issues that must be resolved in order to achieve orientation. Many relate to conceptual models that underlie representations and interfaces. These have to be resolved in general, i.e. outside the architectural domain. Still, they are also relevant to a number of representation issues, such as selectivity as a result of different conceptual frameworks. The architectural focus on buildings tends to eliminate extrinsic elements like trees because they are considered to be obstacles to the viewer rather than

parts of a scene.

In the framework of applications like architectural guides and real-estate information systems, orientation is assisted by the depiction of routes to the points of interest. Even though the depictions are static, their direct relationship to dynamic actions (movement) is frequently sufficient for elucidating the position of the user relative to landmarks, street crossings and other features. Further support to orientation can be provided by the information retrieved from the multimedia databases of buildings that operate in the background. These can provide visual cues that e.g. compensate for the lack of three-dimensional terrain images in navigation systems. Identification of buildings is also simplified by images in the multimedia databases. Orientation is especially assisted by views from critical position, as well as from panoramic views with limited sensitivity to viewpoint. The colour quality of these images is of importance not least because of the viewing limitations of mobile devices and the variable conditions they are used under. Finally, orientation can be augmented by dedicated facilities such as special-purpose emitters or visual matching of e.g. photographs made with the device to indexed views of models.

Special-purpose emitters are a necessity in the case of facilities management, as GPS cannot be expected to perform adequately inside (large) buildings while other networks may suffer too much from interference from each other or the environment. Moreover, emitters can be linked to sensors that monitor specific aspects and provide a fuller picture of the use and behaviour of a building (Jeng, 2005). Visual recognition of location and orientation inside buildings is aided more by two-dimensional than three-dimensional images but the latter are also important for inspection and evaluation purposes (e.g. the state of a wall at the time of the previous inspection), as well as for on-site diagnoses that rely on information on normally invisible aspects or sub-systems.

Selection

Identification of a mobile device's location can trigger a selection of buildings in a database. This is performed primarily through proximity searches that search for points of interest within a given radius from the current location. The geometric proximity can be refined by topological measures. For example, evaluation of the routes that bring the user to these points of interest is useful in the case of architectural guides and arguably critical to real-estate information systems because it indicates the resistance of intervening barriers like main roads, railway lines or other elements that subdivide a physical space into distinct zones.

Selection also depends on ad hoc criteria that describe a user's requirements or preferences. In architectural guides these could reflect interest in a period or style, a particular architect or a building type. Such preferences could be explicitly stated by the user or be learned by the system on the basis of user actions such as annotations or the length of a visit. In real-estate information systems explicit requirements can be stated in the form of a brief (size and structure of the organization to be accommodated), which is then matched to representations of available properties (Steijns and Koutamanis, 2005). In all cases selection should take into account the fuzziness of most selection criteria and of their matching to stored information: rather than making definite choices a retrieval system should prepare multiple, gradually narrower or even overlapping sub-selections that can be manipulated (query refinement) interactively through relevance feedback (Koutamanis, 1995).

A striking aspect of retrieval and learning facilities for making a selection is their dependence on architectural knowledge. Well-defined typologies of buildings are of obvious significance to the description and classification of points of interest in a database, as they provide indexing terms and hierarchical or heterarchical relationships between terms. The interpretation of user criteria into search terms is similarly dependent on codifications of domain knowledge.

Interaction

Design information management systems are the most demanding of our applications in terms of two main forms of interaction. The first is interaction with information in a system and focuses on the temporal dimension: even in asynchronous situations we expect users to handle primarily the latest information, using earlier states mainly as sources on a relevant chain of actions. The second is interaction between different users, both through the manipulation or communication of information and in synchronous situations. Being cognizant of the actors that have contributed to a particular problem, the extent, nature and history of their contributions or actors that may have to deal with the consequences of a decision makes the social dynamics of a situation explicit and relationships between actors and aspects explicit. While mobile devices are too limited to form the backbone of a design meeting, they can act as digital notepads that provide summary overviews, notifications on specific parts or issues, informal communications and personal annotations. As such they complement the more extensive information systems and computing facilities required in design information processing and communication (Koutamanis, 2005b).

Recognition of relevant actors, aspects and information in design information management applications relies partially on pragmatic information that permits direct identification or supports indirect and frequently tentative identification. For example, the log-in name of a user is generally sufficient for recognizing his ownership of a specific aspect or particular information. Similarly, knowing who else is logged on to the same system in the immediate area of a device suffices for identifying the identity and role of other participants to a synchronous situation. Moreover, keeping track of the symbols or parts of a design manipulated by a user (both in terms of frequency and with respect to extent of change) identifies focal points in the design and the approaches different actors take to them. This adds to the correlation of actors and aspects that can be derived

from the de facto ownership of particular aspects by specific specializations. Building information models can arguably provide the basic network of actors, aspects and parts for structuring such actions and relationships.

However, information models and standards may be insufficient for recording and retrieving temporal information, even if complemented with versioning facilities. Abstraction is probably a more useful indication, as it reflects a design stage with more accuracy than time stamps (including feedback to earlier stages). This makes design representations (especially multilevel ones) a valid reference frame also for the temporal dimension in building information models and design information management systems. An important function of such representations relates to the learning potential of a system: recording actors, states and subjects (e.g. who consults whom, when and why) in a comprehensive and precise manner returns stereotypical situations and focal points that can guide identification of relevance in the same as well as subsequent projects.

Representation issues

The integration of domain knowledge in mobile information processing is essential for not only adding content but also context to architectural and building applications. In particular architectural representations appear to provide a usable basis for most processes relating to space (Barker & Dong, 2005). However, it should be noted that there is a tendency to define spatial entities opportunistically or even arbitrarily (Lai et al., 2006; Oh et al., 2006), relying on tagging for e.g. space recognition (Chiu et al., 2006). Such problems arguably relate to an assumption that seems to underlie approaches to ubiquitous computing in architecture and buildings and related research, namely that the built environment is a reflection of architectural design representations: each building element should be a self-aware, integral and discrete entity capable of reporting on its state and receiving behaviour instructions. This expresses

not only the designers' viewpoint but also the users' perspective albeit at a high abstraction level. Most actions and activities in and around buildings involve interaction between a user's anatomy and a conceptually discretely building component such as a door but generally relate to a building or spatial object. For example, the action of entering or leaving a space may focus critically on a door or a door handle and the way they operate to accommodate the user's passage through a more. Still, in most cases this is a brief interlude to a wider and longer plan of actions with respect to a wider spatial framework such as a couple of spaces, e.g. enter the bedroom to go to bed.

In the interests of design integration and continuity it is probably wise to accept the traditional dual representation of building elements and spaces as a reference frame to mobile information processing applications too. However, the integrity of such entities outside design tasks can be less stable and more superficial than frequently assumed. In a space users but also designers distinguish between zones, corners and other parts which may accommodate an activity integrally, i.e. activities can be further localized in a space: my part of the office I share with three others. Also interaction with a building element often amounts to interaction with an interface (e.g. a door handle rather than the door itself or as a whole) or with specific surfaces, which also act as abstractions of elements that bound a space (floors, walls, ceilings).

Many changes relate to the life cycle of a design or building: as we move from one stage to another building elements may disintegrate into components with a different temporal and spatial continuity and again regroup in different combinations. In most design stages a wall is treated as a single integral entity but in reality it consists of several layers, some of which cannot be reduced to discrete components but remain amorphous, e.g. plaster and paint layers. Moreover, some layers combine with the same layers of other elements to form more general (infra)structures such as services and load-

bearing structures or wider agglomerations such as the paint which is applied indiscriminately to different surfaces of the interior of a room. Such changes can be traced back to constraints from construction processes and equipment, interfacing of components and other pragmatic conditions of building. As a result, this fuzziness of building elements can be of considerable significance to a number of design aspects and is central to most facets of building production including logistics.

It is rather surprising that differences between building elements and similar entities in design representations on the one hand and components and materials in construction on the other appear to have attracted little attention in studies of industrialization in building construction. The reason is arguably most studies follow: designing in industrialized building approaches derives largely from the constraints of construction systems, i.e. design primitives are identical to or directly derived from construction primitives. From our point of view the representational basis for the integration of architectural content and context in mobile information processing remains probably the only solution for problems of comprehensiveness and relevance. However, as the applications involve multiple actors, viewpoints and abstraction levels, as well as multimode communication it is advisable to adopt modular strategies that integrate multiple representations and sensory or behavioural information from various sources, from the design brief to RFID tags in building components (Chiu et al., 2006).

Implementation issues

The choice of flexible modular representations as the basis for domain knowledge in mobile information processing has direct consequences on the choice of implementation environments. Rather than relying on fixed symbols at a single abstraction level these representations should be capable of re-packaging information at a variety of specificity levels and from different points of view which relate

to different users, aspects or states. The resulting modules should be linked by means of constraint propagation networks that perform three main functions that connect functionally or structurally related modules, correlate different abstraction and specificity levels, and provide focused feedback to user actions and queries on the basis of the above two linking functions.

From a computational viewpoint such a system can be implemented in a blackboard framework (Engelmore and Morgan, 1988), where various modules participate in a process. Each module has continual access to the current state of the process and contributes opportunistically to the solution of a problem. Problems are generally solved in an incremental fashion as each module and corresponding agents come into action following external requests or changes in the data (Chen and Chiu, 2006)

In terms of representation, information in the building database can be ordered into two overlapping hierarchies, an abstraction hierarchy and a part-of hierarchy. Each entity in the database is described in three interconnected data files: geometry, entity classification (with links to information standards and models) and project-specific data. Fuzziness in entity definition increases as one goes up in the abstraction hierarchy and rather less in positioning as one moves up in the part-of hierarchy (Chen and Chiu, 2006; Koutamanis, 2005a).

References

- Abowd, G.D., Atkeson, C.G., Hong, J., Long, S., Kooper, R. & Pinkerton, M.: 1997, *Cyberguide: A mobile context-aware tour guide*. *Wireless Networks*, 3, pp. 421-433.
- Barker, D. & Dong, A.: 2005, *A representation language for a prototype CAD tool for intelligent rooms. Smart architecture: Integration of digital and building technologies*. Savannah, Georgia, ACADIA.
- Berridge, P., Brown, A. & Knight, M.: 2002, *One city to go*. In Rafi, A. M. E., Khong, C. W., Neo, M., Neo, K. T. & Ahmad, S. N. A. S. (Eds.) CAADRIA 2002. Proceedings of the 7th Conference on CAAD Research in Asia. Cyberjaya, CAADRIA.
- Bunyavipakul, M. & Charoensilp, E.: 2003, *Designing the virtual design studio system for collaborative work on PDA*. In Choutgrajank, A., Charoensilp, E., Keat-rangamala, K. & Nakapan, W. (eds.) CAADRIA 2003. Proceedings of the 8th Conference on CAAD Research in Asia. Seoul, CAADRIA.
- Burrell, J. & Gay, G.K.: 2002, *E-graffiti: evaluating real-world use of a context-aware system*. *Interacting with Computers*, 14, pp. 301-312.
- Chen, S.-Y. & Chiu, M.-L.: 2006, *Agent-based smart skins*. In Kaga, A. & Naka, R. (eds.) CAADRIA 06. Proceedings of the 11th Conference on CAAD Research in Asia. Kumamoto, CAADRIA.
- Cheng, N.Y.-W. & Lane-Cumming, S.: 2003, *Using mobile digital tools for learning about places*. In Choutgrajank, A., Charoensilp, E., Keatruangkamala, K. & Nakapan, W. (Eds.) CAADRIA 2003. Proceedings of the 8th International Conference on Computer Aided Architectural Design Research in Asia. Bangkok, CAADRIA.
- Cheverst, K., Davies, N., Mitchell, K., Fiday, A. & Efstratiu, C.: 2000, *Developing a context-aware electronic tourist guide: some issues and experiences*. Proceedings of the CHI'00. ACM international conference on human factors in computing systems. New York, ACM Press.
- Chiu, M.-L., Chiang, B., Lee, G.-C. & Tseng, H.: 2006, *House sense*. In Kaga, A. & Naka, R. (eds.) CAADRIA 06. Proceedings of the 11th Conference on CAAD Research in Asia. Kumamoto, CAADRIA.
- Engelmore, R. S. & Morgan, A. J.: 1988, *Blackboard systems*, Reading, Massachusetts, Addison-Wesley.
- Ibrahim, M. M., Krawczyk, R. J. & Schipporiet, G.: 2004, *A web-based approach to transferring architectural information to the construction site based on the BIM object concept*. In Choi, J.-W. & Lee, H. S. (eds.) CAADRIA 2004. Proceedings of the 9th Conference on CAAD Research in Asia. Seoul, CAADRIA.
- Jeng, T.: 2005, *Advanced ubiquitous media for interactive space*. In B. Martens & A. Brown (eds.) CAAD Futures 2005. Dordrecht, Kluwer.

- Kaga, A., Miyagawa, A., Kawaguchi, M., Yeo, W. & Fukuda, T.: 2006, Landscape evaluation system using a 3D space model and a cellular phone with GPS camera. In Kaga, A. & Naka, R. (eds.) CAADRIA 06. Proceedings of the 11th Conference on CAAD Research in Asia. Kumamoto, CAADRIA.
- Knight, M. W., Brown, A. G. P. & Smith, J. S.: 2006, Digital terrain meshes from GPS in urban areas: A practical aid to city modelling. In Kaga, A. & Naka, R. (eds.) CAADRIA 06. Proceedings of the 11th Conference on CAAD Research in Asia. Kumamoto, CAADRIA.
- Koutamanis, A.: 1995, Recognition and retrieval in visual architectural databases. In Koutamanis, A., Timmermans, H. & Vermeulen, I. (eds.) Visual databases in architecture. Recent advances in design and decision making. Aldershot, Avebury.
- Koutamanis, A.: 2005a, Fuzzy design modelling. In Emmitt, S. & Prins, M. (eds.) Proceedings of CIB W096 architectural management. Lyngby, CIB World.
- Koutamanis, A.: 2005b, The structure of a group design room. In Emmitt, S. & Prins, M. (eds.) Proceedings of CIB W096 architectural management. Lyngby, CIB World.
- Lai, C.-P., Lan, J.-H. & Chiu, M.-L.: 2006, Space tags: A digital guide to the cultural district of Anping. In Kaga, A. & Naka, R. (eds.) CAADRIA 06. Proceedings of the 11th Conference on CAAD Research in Asia. Kumamoto, CAADRIA.
- Lertlakkhanakul, J., Lee, I., Kim, M. & Choi, J. W.: 2005, Using the mobile augmented reality techniques for construction management. In Bhatt, A. (ed.) CAADRIA 2005. Proceedings of the 10th Conference on CAAD Research in Asia. Seoul, CAADRIA.
- Nomura, Y. & Kishimoto, T.: 2005, Visualization of tourists' behavior and activity using GPS and GIS in Kamakura City. In Bhatt, A. (ed.) CAADRIA 2005. Proceedings of the 10th Conference on CAAD Research in Asia. Seoul, CAADRIA.
- Oh, S., Kidawara, Y., Tanaka, K. & Nagafune, T.: 2006, A prototype system for use in designing ubiquitous environmental spaces. In Kaga, A. & Naka, R. (eds.) CAADRIA 06. Proceedings of the 11th Conference on CAAD Research in Asia. Kumamoto, CAADRIA.
- Oppermann, R. & Specht, M.: 1999, A Nomadic Information System for Adaptive Exhibition Guidance. Archives and Museum Informatics, 13, pp. 127-138.
- Persson, P., Espinoza, F., Fagerberg, P., Sandin, A. & Cöster, R.: 2002, GeoNotes: A location-based information system for public spaces. In Höök, K., Benyon, D. & Munro, A. (eds.) Designing information spaces: The social navigation approach. London, Springer.
- Shen, Y.-T. & Teng, T.-S.: 2005, Personal mobile device for situated interaction. In Bhatt, A. (ed.) CAADRIA 2005. Proceedings of the 10th Conference on CAAD Research in Asia. Seoul, CAADRIA.
- Steijns, Y. & Koutamanis, A.: 2005, A briefing approach to Dutch school design. In Emmitt, S. & Prins, M. (eds.) Proceedings of CIB W096 architectural management. Lyngby, CIB World.
- Tedrumpun, T. & Nakapan, W.: 2004, Site measurement with combination of pocket PC and global positioning system for preliminary architectural design process. In Choi, J.-W. & Lee, H. S. (eds.) CAADRIA 2004. Proceedings of the 9th Conference on CAAD Research in Asia. Seoul, CAADRIA.
- Wang, P.-H. & Shih, N.-J.: 2002, A preliminary application of a PDA-based OODB system for construction information management. In Kosszewski, K. & Wrona, S. (eds.) Connecting the real and the virtual - design education. Warsaw, eCAADe.
- Yabuki, N., Shimada, Y. & Tomita, K.: 2002, An on-site inspection support system using radio frequency identification tags and personal digital assistants. In Agger, K., Christiansson, P. & Howard, R. (eds.) Distributing knowledge in building. Aarhus, CIB.