ITcon

www.itcon.org - Journal of Information Technology in Construction - ISSN 1874-4753

A ROAD-MAP TO PERSONALIZED CONTEXT-AWARE SERVICES DELIVERY IN CONSTRUCTION

PUBLISHED: August 2009 at http://www.itcon.org/2009/30

EDITORS: Kazi A S, Aouad G, Baldwin A

Zeeshan Aziz, Research Associate,
University of Illinois at Urbana-Champaign
zeeshanaziz@illinois.edu

Chimay Anumba, Professor
The Pennsylvania State University,
anumba@engr.psu.edu

Feniosky Peña-mora, Professor
University of Illinois at Urbana-Champaign,
feniosky@illinois.edu

SUMMARY: *Existing mobile IT applications in the construction industry are constrained by their reliance on static methods of information delivery, which are often not appropriate to meet changing work demand resulting from dynamic project conditions. This paper focuses on a new interaction paradigm i.e. context-aware information delivery (CAID), which promises to make information provisioning more responsive to workers' changing work demands. A roadmap to personalized CAID in construction is laid out, with a focus on creating a pervasive user-centred intelligent work environment capable of serving relevant information needs of busy construction professionals by intelligent interpretation of their context. Research approach includes use of scenario planning method. Face-to-face unstructured interviews were arranged with 28 industry and technology experts for scenario validation and provided input for the road-mapping exercise. The research demonstrates that the realisation of the CAID vision is within reach and will tremendously enhance the value proposition of mobile information technology in the construction industry. Context-relevant and personalised information delivery will save valuable time and has the potential to improve efficiency and productivity. It can make construction ICT applications and worker's immediate work environment more responsive to work demands, thereby allowing better management of construction projects. A key challenge is to link various technology enabling elements with methodological, cultural, social and organisational aspects specific to the construction industry. This would require a multi-disciplinary approach requiring input from different fields, including computer science, ergonomics, social studies and the construction industry.*

KEYWORDS: *Context-aware Information Delivery, Roadmap, scenario planning*

REFERENCE: *Aziz Z, Anumba C, Peña-mora F (2009) A road-map to personalized context-aware services delivery in construction, Journal of Information Technology in Construction (ITcon), Vol. 14, Special Issue Next Generation Construction IT: Technology Foresight, Future Studies, Roadmapping, and Scenario Planning, pg. 461-472, http://www.itcon.org/2009/30*

1. INTRODUCTION

In recent years, the construction industry has faced an increasingly competitive pressure to implement techniques that can reduce project duration and cost, whilst improving productivity and performance. This pressure is often result of changing industry dynamics where clients are demanding better value-for-money, higher quality, shorter construction cycle times and access to the up to date information, produced at any point in the project life cycle and supply chain (Aziz et al., 2006). The need for innovative ways to face these challenges has long been recognized. Many challenges in existing construction processes arise from poor access to the right information at the right time for timely decision-making and from a general communication breakdown between project participants (Kondratova et al, 2003). Quality, quantity and timing of information is important, as it can either hinder or facilitate successful results (Garza et al, 1998). The mobile and information intensive nature of construction projects, the unstructured and dynamic nature of the construction site and hazards and difficulties presented by on-site work necessitates the use of intelligent ways to support mobile construction workers. Aforementioned intelligent information provisioning requirements coupled with significant advances in mobile communication technologies in terms of improved wireless bandwidth, quality of service, cost, processing power, battery life and hardware to support real-time connectivity has enabled the opportunity for providing a CAID support infrastructure for mobile construction workers.

Current deployment of mobile information technology (IT) applications for the construction industry has focused on adapting off-the-shelf commercial products to the construction market without a detailed understanding of the contexts in which these systems will be used, and user requirements. Information provisioning to for construction workers is seen as a "simple" static delivery of project data, plans, technical drawings, audit-lists etc, without taking into account mobile worker changing context and dynamic project conditions. Many commercially available solutions typically use asynchronous methods of communication with no consideration of user-context, by downloading field data from mobile devices onto desktop computers and then transferring this information into a project information repository. Even where real time connectivity needs are addressed, the focus is on delivering static information to users such as project plans and documents or access to project extranets. Similarly, most of the commercially available mobile applications for the construction industry target management staff (e.g. project management, quality assurance, health and safety etc.) and are designed primarily to deliver a pre-programmed desktop computer functionality for mobile users without any consideration of the fact that operational context of a mobile construction worker is much different to that of an office based construction worker. These applications are not aware of who the user is, his/her profile/preferences, what task (s)he is involved in and what existing project conditions are. As highlighted by Menzel et al (2002), the construction industry is still lacking software systems designed to support specific on-site tasks, provide helpful guidance through these tasks, and support intelligent methods of human-computer interaction that take into account the context of on-site construction and supervision activities. This lacking often leads to a contrast between mobile applications functionality and actual data requirements. As a result, on many occasions technology has failed to meet information requirements of mobile construction workers (Aziz et al, 2004).

In contrast to the existing static information delivery approaches, the construction work, by its very nature, is dynamic. Due to the unpredictable nature of construction projects, different activities are often difficult to anticipate. Resultantly, construction project plans, drawings, schedules, project plans, budgets etc have to be updated periodically. Also, the context of mobile workers operating on-site is constantly changing (such as location, task involvement, construction site situations and resulting hazards, etc) and so does, their information requirements. Thus, mobile construction workers require that supporting systems understand who they are (e.g. their role, language preferences, skills profile, etc), where they are located and existing project conditions to deliver the right information at the right time on as-needed basis. Such a capability is possible through CAID which adds an additional layer to real time wireless connectivity (Aziz et al, 2006) offering the following benefits:

- Delivery of relevant data based on the worker's context (such as profile, task-at- hand, location, etc), thereby eliminating distractions related to volume and level of information;
- Reduction in user interaction with the system by using context as a filtering mechanism to deliver only relevant information. This has the potential to increase usability, by decreasing the level of interaction required between mobile devices (which are constrained by limited interface size) and end-users.

In this respect, CAID technologies can play a critical role by bridging the gap between the virtual world (as enabled by elements of ICT infrastructure) and the physical world of actual construction operations. In this paper, context-awareness is used as an umbrella term to describe technologies that be can be used to bridge this gap that would make construction applications aware of on-site activities. This includes technologies that can be used to capture user-context and help to reason about it and take subsequent intelligent actions, based on the interpreted context. Some of these technologies (such as user profiling, ubiquitous computing, RFID and sensor networking) are discussed in more detail in Section 2.

The rest of the paper is organised as follows. Section 2 reviews the concept of CAID and discusses some of the enabling technologies. The research method followed in this research is discussed in Section 3. Section 4 discusses a roadmap for the realisation of CAID vision and its various enablers and barriers. Various recommendations and conclusions are presented in Section 5.

2. CONTEXT-AWARE INFORMATION DELIVERY & ENABLING TECHNOLOGIES

The concept of CAID as discussed in this paper centres on the need to provide mobile construction workers with highly specific information and services on an as-needed basis, by intelligent interpretation of their context. Pashtan (2005) described four key partitions of context parameters which are often used in context aware applications (Figure 1). The concept goes beyond merely capturing various context parameters (such as user-identity, location, temporal information, resource availability and task) and encompasses the creation of a pervasive, user-centred mobile work environment, capable of supporting mobile construction workers by intelligent interpretation of their situation, thereby helping them to take more informed decisions. Emerging complementary technologies such as ubiquitous computing, user profiling and sensor networking enables the capture of many other context parameters.

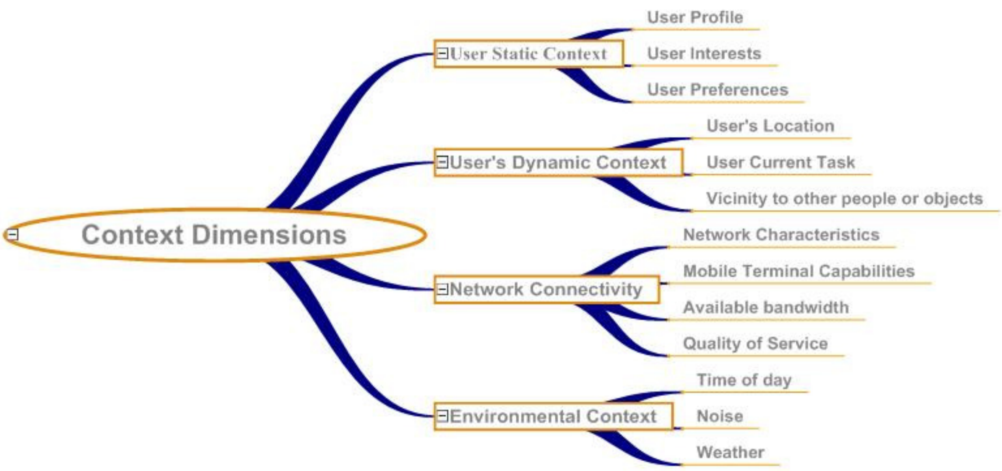

FIG. 1: Context Dimensions (Pashtan, 2005)

Context-aware computing is an established area of research within computer science. The application of context-awareness for mobile users has been demonstrated in a large number of applications, across multiple disciplines, including mobile, ubiquitous and wearable computing, augmented reality and human computer interaction. Application of context-aware technology in the construction industry remains limited (Aziz et al., 2006). Some of the enabling technologies for CAID are discussed below.

- *Location-Baed Services* refers to applications that utilise the user/object location knowledge to provide relevant information and services. An accurate and timely identification and tracking of construction components are critical to operating a well-managed and cost efficient construction project (Furlani et al, 1999). Behdzan et al (2008) has reviewed application of various outdoor and indoor location tracking technologies for facilitating construction operations.

- *Ubiquitous Computing* is an emerging paradigm of personal computing, characterised by the shift from the dedicated computing machinery (requiring user's attention e.g. PCs) to pervasive computing capabilities embedded in everyday environments (Weiser, 1991). The vision of the ubiquitous computing require a wide-range of devices, sensors, tags and software components to interoperate. The benefits of ubiquitous computing are perceived as ubiquitous access to information, seamless communications based on wireless technologies and computer mediated interaction with the environment through sensing, actuating and displaying (O'Sullivan et al, 2003). According to Ailisto et al (2003), the key functionality to implement the ubiquitous computing functionality include context-awareness (the ability to capture user context such as location and other sensory data), service discovery (finding available service providers in a wireless network), awareness of user requirements/preferences (making the user's desires known to other service providers), user-interface design (touch screen, voice input, speech output, etc.), the ability to match user requirements to services; and machine learning to improve performance over time, and adapt to better meet the user's needs. Relevance of the ubiquitous computing for the construction industry lies in the fact that these technologies have the potential to make construction collaborative processes and services sensitive to the data available in the physical world (Anumba et al,2003a) enabling a wide range of applications from field data collection, to materials management, to site logistics.

- *Sensor Networks* – In the construction industry, sensor networks can be used to monitor a wide range of environments and in a variety of applications, including wireless data acquisition, machine/building monitoring and maintenance, smart buildings and highways, environment monitoring, site security, automated tracking of expensive materials on site, safety management and many others (Aziz et al., 2002). In future, using different hardware technologies such as wireless communications, smart materials, sensors and actuator, it will be possible to add additional context dimensions, allowing for better mapping of the physical and virtual world.
- *RFID* –The term RFID describes technologies that use radio waves to identify individual items using tags. Being radio based, it has a non line-of-sight readability. RFID technologies can be used for a wide range of applications to enhance construction processes including materials management, location tracking of tools/equipment, safety and security, supply-chain automation, maintenance and service provisioning, document control etc.
- Profiling technologies allow the delivery of personalised information to users, based on their profile and device capabilities. A W3C working group recommends the use of the CC/PP (Composite Capability/Preference Profiles) (CC/PP, 2003) framework to specify how client devices express their capabilities and preferences to the server that originates content. Using the CC/PP framework, information collected from the terminal can be tagged with relevant context parameters (such as location and device-type). It is also possible to enable selection and content generation responses such as triggering alarms or retrieving information relevant to the task at hand.

3. RESEARCH METHOD

The encompassing theme of this research was the emerging field of context-aware computing and its future applications for the construction industry. From this viewpoint, applicability of various future research methods including future extrapolation, exploratory, participatory, normative, scenario-planning and future modelling techniques were reviewed. The emerging nature of the CAID technologies and the huge amount of uncertainties with regards to application in the construction industry (such as application scenarios, business models, technology robustness, interoperability and costs) undermine the basic assumption of the future extrapolation (i.e. the future is an extension of the past) and future modelling (i.e. future can be modelled based on the events of the past) methods. Normative methods were not considered relevant for this research because of their underlying assumption that there is a one single right future with the consequence of aiming to deduce it. In contrast, because of the high level of uncertainties involved with regard to context-aware technology applications in the construction industry, this research effort relied on the scenario-planning assumption that there is no single best answer since the future is uncertain and unpredictable (Heijden, 1996). Scenarios are known to offer greater advantages over other forecasting methods when uncertainty is high and historical relationships shaky (Fahey & Randall, 1998). As part of this research, various futuristic research scenarios were developed (Aziz et al., 2004). Scenarios were set in a "day in the life of" situations of a mobile construction worker and were generated to serve typical information needs (such as construction procurement, project management, services provision, task allocation). The key objective of generating realistic construction scenarios was to take the focus away from the underlying technology and to find out more about key drivers and barriers and utility of a particular application from the construction industry perspective. Also, scenarios were used as a basis to stimulate new ideas and themes and to understand the construction industry's needs for future CAID technologies. It is from an understanding of these problems that a list of construction industry needs for CAID was drawn-up. The time horizon chosen for the scenarios was 10 years. Given the existing uncertainties involved with various enabling technologies, this time frame was considered realistic. This long term focus was also important to ensure that the industry takes the right steps, in the short term, to effectively adapt to the emerging technologies in the long term.

In order to have a more credible and concrete validation of scenarios and to elicit different perspectives, face-to-face semi-structured interviews were conducted with industry experts. The key objective of scenario validation was to pose the question of the next generation context-aware mobile applications in the construction sector and to identify the industry's needs and application areas with the maximum potential. The Scenario-based User Needs Analysis (Helvert et al, 2003) method was used to translate user needs identified during the scenario validation process into system design goals. These needs were subsequently combined into a common table and a "Needs Hierarchy" was generated, which served as the basis for the system specification. Identified needs were then mapped to available technologies, resulting in a communications system architecture and deployment models (i.e. Unified Modelling Language use-cases). The context-aware information delivery prototype was developed on a Pocket-PC platform using Microsoft VisualStudio.net implementation environment . Prototype evaluation involved expert and end-user evaluation and a workshop. Data generated at various phases of research was used to develop roadmap.

The research procedure included literature review on Context-Aware technologies, development of a conceptual framework for context-aware information delivery, development of futuristic deployment scenarios in the construction industry context, validation of these scenarios with the construction industry and technology experts, identification of user needs, development of the prototype system based on the user needs, evaluation of the prototype system with industry experts, and future road-mapping to identify issues and gaps that need to be filled. Various research tools used in different phases of research are summarised in Table 1.

TABLE 1: Tools used in various phases of research

Research Tasks / ***Research Tools***	Technology and Literature Review	Scenario Generation	Scenario Validation	User Needs Analysis	System Design	System Development	System Evaluation
Personal Document Analysis	√						
Semi-Structured Interviews (Using Laddering Technique)			√				√
Scenario-planning Method		√					
Scenario Based User Needs Analysis				√			
Use-case modelling					√		
Rapid Prototyping						√	

4. ROADMAP

Figure 2 presents a roadmap for the realisation of CAID vision in Construction, while Table 1 summarises key steps that need to be undertaken for realisation of the roadmap in short, medium and long term. As illustrated in Figure 1, a number of challenges must be addressed including personalisation and user profiling, development of context-aware interfaces, contextually integrating design and project management using approaches such as Building Information Modelling, Context-aware procurement and supply chain and intelligent construction job-site. First challenge refers to development of a context sensitive dynamic user profile interface to ensure data delivery to mobile construction workers based on their skill levels and preferences and to enable intuitive adaptive interaction. Applications of voice based technologies would enable hands-free working for mobile workers. As a result of increasing globalisation, often, different languages, culture and skill sets, pose a significant challenge to effective construction communications. Second key challenge relates to development of

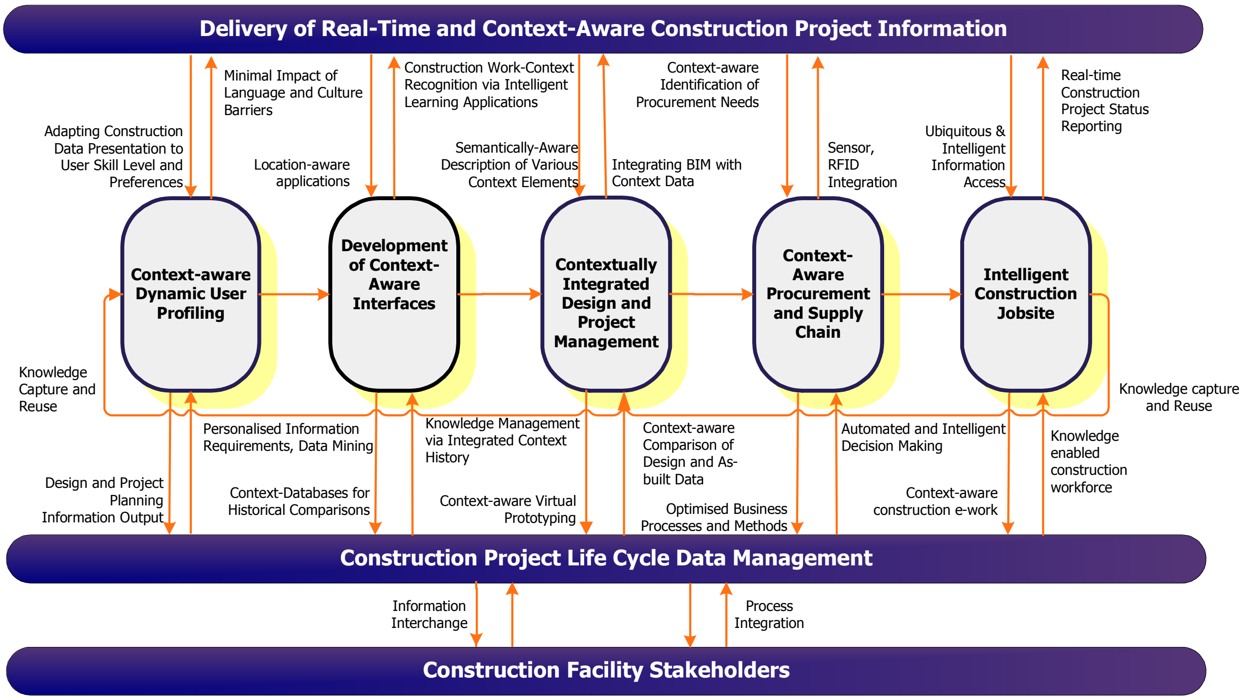

FIG. 2: Context-aware services delivery in Construction roadmap

context-aware interfaces and applications for mobile workers to enable effective project management and mobile e-work. Such interfaces will help delivery of precisely needed context-relevant information to the right person at the right time. Development of context databases will enable historical comparisons and knowledge management. Third challenge relates to integration of design and project management. The value of existing approaches to virtual building modelling is highly depended on the perspectives of the end user, which changes from time to time in line with changes in the project and user context. Thus, a key objective of integrating design and project management with context-awareness is to understand changes in the context of the user (such as having a knowledge of who they are, where they are located, what tasks they are involved in, what stages/aspects of the building model they are interested in or responsible for, etc.) and to deliver the right information to the right worker at the right time, on as-needed basis. Fourth challenge relates to overcoming the boundaries of communication set by heterogeneous networks by enabling mobile handover and seamless communication between wireless and wired networks. Thus, there is a need to use open-standard approaches, to allow different applications and users to discover services and capabilities and to integrate dynamically. Fifth challenge relates to the creation of an intelligent work environment for construction workers, by bringing together key technology threads such as Ubiquitous Computing, Wireless Sensor Networking, tagging and location tracking technologies, as part of the context-capture layer. Better awareness of the user-context, as enabled by the aforementioned technologies can be used for a wide range of applications on the construction site, including those that increase human productivity (such as location-tracking of tools), increase safety on the construction site (such as tracking workers near machines) and automate various tasks (such as automated data capture). Realisation of the roadmap vision will have a wide ranging impact on construction industry by enabling a wide range of new services for supporting site-work (e.g. on-site data collection, using context knowledge for quality control/assurance, concurrent data management between site activities and processes), for site-automation (e.g. intelligent data processing – end of shift reports, knowledge management and distribution, quality enhancement through location-aware analysis of information needs) and project management (e.g. profile based task allocation, location based content delivery, context-aware site logistics, site security and Health and Safety, personalised task allocation and schedule updating, dynamically updating project management plans based on user-profile and from point of work, dynamically changing priority of tasks assigned to workers, linking personlised task lists with project management plans, etc).

TABLE 1: Context-Aware Information Delivery Roadmap

Issues & Description	Short-term (0 to 4 years)	Medium Term (4 to 8 years)	Long Term (8 to 12 years)
Approaches to Context-Modelling and Context Capture A well-designed context-modelling and retrieval approach is essential for implementation of a context-aware system within the construction industry	1) Detailed context modelling of various construction activities and categorisation of different data types related to construction project management 2) Structured and Semantically-aware description of various context elements and construction documents; 3) CAID to support construction workers and facilitate decision making using dimensions that are easy to capture using existing technologies (e.g. location, time, user-profile, hardware type, project status, network conditions)	1) Include more parameters in CAID paradigm using emerging technologies such as Sensor Networks 2) Integration of captured context with context-history as part of organisation's knowledge management efforts (e.g. what happen in past in a particular situation and what actions should be taken under the current context). 3) Integration of context knowledge with existing construction project management applications to enable intelligent data processing 4) Development of context databases to allow for historical comparisons and effective knowledge management	1) Address more complex dimensions of CAID e.g. context history, work habits, personalised knowledge requirements 2) Application of emerging technologies to capture contextual information to accelerate and optimise the collaboration process in a dynamic project environment 3) Integrate with innovations in other related areas e.g. data mining, knowledge reuse, nd modelling, Industry Foundation Classes.
Personalization & User Profiling Key objective is to allow delivery of personalised information to users, based on captured context parameters such as location, task, device capabilities, project conditions, etc.	1) Enhance existing project management applications using user-profiling technologies to to personalize data delivery to meet needs and requirements of construction workers 2) Developing applications that are simple to use and customised to worker requirements through better user profiling and understanding of user preferences	1). Development of dynamic and intelligent user interfaces for optimized performance and enhanced user interaction for better understanding of construction work context using incremental learning algorithms. 2) Develop system that could adapt to user skill level and preferences 3) Use mobile devices as back-up tools to support drawing information from Building Information Models 4) Context-aware delivery of Health and Safety information and warnings	1) Minimize the impact of cultural and language differences through highly personalised user interfaces using voice/icons based approach 2) Enhanced personalization to enable mobile devices to recognize user identity, words and commands.

Issues & Description	Short-term (0 to 4 years)	Medium Term (4 to 8 years)	Long Term (8 to 12 years)
Application of Sensors and Tagging Technologies Application of various sensors and tagging technologies (e.g. RFID) in development of an intelligent construction site	1) Address process related issues e.g. which objects to tag, how to tag, how to audit tags, using tags/sensors during operations and maintenance stage 2) Application of various off-the-shelf tagging technologies (e.g. RFID, Barcodes) to support construction processes	1) Use of intelligent tags, with data storage and networking capabilities 2) Application of tagging technologies for a wider set of applications including logistics, materials management, plant management, project management etc.	1. Creation of an intelligent work environment where all objects and machinery will have an identify and could establish links with other objects to take intelligent decisions and automate processes 2. Application of technologies in all phases of project
Ergonomics Identified ergonomic issues included difficulty in data input, size limitations of mobile devices interface and difficult in device usage in outdoor environments	1) Use of easier data input mechanisms e.g. Graphical symbol based, thumb based, infrared based keyboards. 2) Using multi-modal interfaces e.g. voice input and output	Enhanced application of multi-modal interfaces e.g. voice input/output, cognitive mapping, virtual keyboards	Further improvements in ergonomics through application of new technologies and processes enabling easier interaction and hands-free operations
Software and Standards Issues Development of software standards and interfaces to meet construction industry's unique requirements for software tools, methods and interfaces	1. Use standardised tools, network technologies, standards, protocols (e.g. J2ME, XML, XMTML, voiceXML, bcXML) and methods to develop pilots and prototypes. 2. Review approaches used in other industry sectors 3. Integration of existing project management interfaces with heterogeneous mobile networks using open standards	1. Platform-independence, interoperability, and shortened development times. 2. Software development and mobile and wireless data access using a standards based approach 3. Industry standard ontologies development 4. Use of IP based technologies to overcome barriers set by heterogeneous networking infrastructure	Achieve goals for platform-independence, seamless handover between multiple networks, interoperability, open standards and shortened development times
Hardware Issues Work environments on construction sites are dynamic and rugged. Thus, hardware used should be able to withstand harsh operational requirements through characteristics such as shock protections and operation in harsh weather conditions.	1. Adapt commercially available off-the-shelf hardware tools e.g. Personal Digital Assistants, Smart Phones to construction market requirement 2. Determine exact environments in which devices are likely to operate and develop necessary protection for hardware to ensure optimal performance	Develop hardware more specifically suited for the construction work environments	Develop multi-function hardware customised to construction work environment

Issues & Description	Short-term (0 to 4 years)	Medium Term (4 to 8 years)	Long Term (8 to 12 years)
Security and Trust Issues Highlighted security and trust issues included vulnerability of corporate data stored on mobile devices, security of wireless networks, technology invading user privacy (e.g. capturing user location, profile, etc) and technology misuse (e.g. access permissions, false data recording)	1. Application of biometrics and voice-recognition technologies to secure off-line data; 2. Use of IP-based wireless technologies (e.g. WiFi, 3G) with better security features; 3. Development of fool-proof applications that would support the construction processes with clear understanding of various construction roles. 4. Address technology application issues such as determining access right issues for users	1. Use broadband wireless (e.g. WiMAX, 3G) technologies to minimise needs for offline data storage 2. Use a multi-disciplinary approach to address issue of trust in information delivery. 3. Improvement of business processes using emerging technologies 4. Develop a fool-proof system to redress problems if they go wrong	Use emerging technologies to further improve security and trust
Organisational and Cultural Issues Identified issues were wide ranging including concerns about technology creating additional workload and industry high worker churn rate, making it difficult to introduce new technology)	1. Make technology work for users – not against them; Let workers see advantages of technology 2. Study impact of new technology on worker's quality of life and involve other disciplines such as study of human behaviour along with application of technology 3. Use language independent icons-based interfaces	1. Adopt a socio-behavioural-technical approach to study construction teams in their work environments 3. Use technologies such as voiceXML to provide multi-language capabilities	1. Integrate Organisational and Cultural aspects in design 2. Support for diverse languages, cultures and work styles through voice enabled interfaces

4.1. ENABLERS AND INHIBITORS TO REALISATION OF CAID VISION

Various enablers and inhibitors to the realisation of the CAID vision were identified during course of this research. Key points are illustrated in Figure 1. Identified inhibitors (figure 1) highlighted the fact that for successful implementation of CAID technologies in the construction industry, it is important to address constraints introduced by technological complexity, cost, user-acceptability and fragmented nature of the construction industry. Various technology related barriers such as lack of available hardware, limited battery life, high deployment costs, security concerns, etc will be gradually addressed as various technologies mature over time. Lack of standard protocols and hardware platforms has increased the complexity of system deployment choices available. Although various wireless technologies such as Bluetooth, IEEE 802.11, GPRS has become defacto standards, many new technologies and protocols are being proposed.

Figure 1 also highlights various enablers of CAID vision. With the decreasing costs and fast pace of mobile-IT related technology growth, it has become possible to address many of the technology related shortcomings of mobile IT deployment in the construction industry. New technologies are emerging which can be used to enhance support for mobile construction workers. Many of these technologies are complementary. It is important to explore how these technologies can effectively be integrated in the construction work environment in order to improve construction processes.

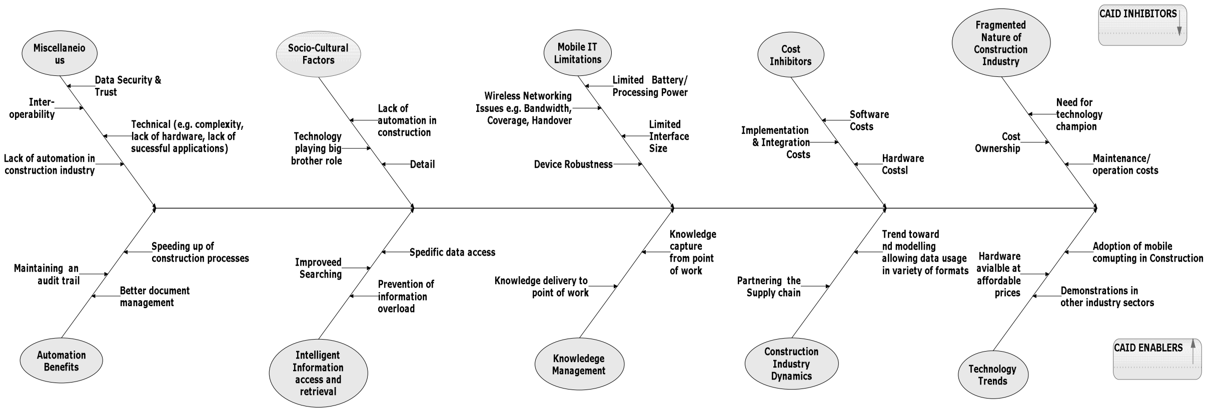

FIG. 3: Enablers and Inhibitors for realisation of CAID vision within Construction

5. CONCLUSIONS AND RECOMMENDATIONS

This paper concludes that realisation of the vision of CAID for construction industry has become possible because of emerging technologies such as ongoing miniaturisation, developments in sensor networking, the increase of computational power and the fact that wireless broadband is becoming technically and financially feasible. CAID opens up new possibilities for leveraging the capabilities of mobile computing in the construction industry by using context as a filtering mechanism to deliver information relevant to the task at hand. Context-aware computing technologies can be used for a wide range of applications in the construction industry including improved site-logistics, object identification, real-time tracking etc thereby enabling the creation of an intelligent mobile work environment. The road-mapping exercise reveals a number of areas for further research and development and for further improvement in the existing construction industry practices. These include:

- The need to investigate how different Architecture, Engineering and Construction/ Facilities Management Sectors could utilize CAID concepts to improve processes
- Privacy of mobile workers and other security (such as integrity of information) and trust issues (such as access permissions) were highlighted during the course of this research. Such issues should be addressed during design and implementation of CAID systems.
- Various limitations of Pocket-PC type mobile devices such as limited screen size, screen visibility, short battery-life and input method could adversely impact the uptake of mobile computing in the Construction Industry. Thus, future research should also address the hardware related issues of mobile devices that constitute barriers to their implementation on construction projects. This should include exploration of various multi-modal interfaces to address the shortcomings related to manual data entry.
- Location is the key factor in context-aware information delivery frameworks. Various questions related to real-time location tracking in construction environments were identified during the validation process. These include: How is the information requirement or context of a worker in the site office different from another operating on the construction site? What will happen in case of overlap of wireless zones i.e. if a user is in a range of two wireless networks, how will the system differentiate his/her exact location context? What level of granularity may be important for on-site operations. Is it possible to define generic logical areas for a construction site (such as site-storage, site-operations, ground Floor etc) for effective CAID? It is important to consider such issues for effective deployment of any future context-aware systems.
- There is a need to integrate context-awareness in existing construction applications. For instance, different types of sensors can possibly be used to capture a wide range of context parameters from the construction site; The captured context information can be integrated with meta-data, to allow better interpretation of the captured context and to provide highly specific data to users on an as-needed basis; Also, construction applications can be developed that can capture the contextual information to provide dynamic support to mobile workers, which reflect their changing context.

- Successful deployment of CAID technologies in the construction industry would require expert input from many disciplines, including Usability/Ergonomics Experts (to ensure that end-user perspective is taken in system design and implementation), technology experts(to ensure that new technology is deployed in an optimal manner), socio-behavioral scientists (to address user-acceptability issues) and construction industry experts (to bring in their knowledge of existing application deployments in the construction industry, and to identify application scenarios that can provide appropriate test-beds for the enabling technologies, etc).
- In recent years, various attempts of implementing CAID technologies in construction industry have had limited success. Major reasons for low uptake of CAID technologies include lack of awareness of the potential benefits of the CAID technologies and lack of appropriate technical knowledge in Construction SMEs to make use of these technologies. This highlights the need for education and awareness at appropriate levels. It is imperative that innovations in mobile computing and CAID should be part of curriculum for student education and training of construction workers to address skills shortage in this area. However, in the short term, such skills shortage can be addressed through on-the-job training and introduction to appropriate tools. Use of mobile tools with multi-modal interfaces (e.g. voice input) and dynamic user profiling to determine user technical level based on the skills profile could be immediately used. Such training in advanced CAID coupled with traditional construction training will provide much needed boost to enhance worker's technical skills.
- Meyer et al (2003) described how research into future computing technologies is often far removed from the needs of the user and as a consequence "the nature of such future systems is often too obtrusive". While there is a need to integrate emerging technologies in the construction work environment, it is also important understand the requirements of end-users in the construction industry, so that the technology is rightly aligned to the needs of end-users. Also, the construction industry is characterised by a very high churn, where construction workforce is always on the move. For this reason, mobile communication devices need to be developed that are very user-friendly to operate. Techniques such as dynamic user profiling, voice input and output can further make the system user friendly. Features such as context-sensitive selection of interesting information, suppression of irrelevant data and information overload can also enhance the usability of mobile applications.
- Taking into account the fact that for many small construction organisations, even the use of computers is relatively new it is important to have well-documented industrial pilot projects on real-life construction environment (or under a simulated environment in case if the technological infrastructre is not readily available). This will further demonstrate the suitability and scalability of these technologies for the construction industry while increasing the industry awareness of the potential benefits. Such projects can also be used for undertaking more detailed user studies.

In summary, delivering context-relevant and personalised information to construction workers has the tremendous potential to save valuable time and improve efficiency and productivity. However, realisation of the real potential of CAID in the construction industry needs to satisfy the constraints introduced by technological complexity, cost, user needs and interoperability. Technology innovations in other areas, such as multimodal interfaces and speech technologies, also need to be integrated. Also, a key challenge is to link various technology enabling elements with methodological, cultural, social and organisational aspects specific to the construction industry. This would require a multi-disciplinary approach requiring input from different fields, including computer science, ergonomics, social studies and the construction industry. This holistic multi-disciplinary approach is essential to address various facets of CAID in the construction industry. Also, to encourage widespread adoption, there is a need for successful industrial case studies. There are numerous potential benefits in providing a CAID infrastructure for the construction industry and it needs to make the necessary investments to realise these.

REFERENCES

Aziz, Z., Anumba, C.J., Ruikar, D., Carrillo., P.M., Bouchlaghem.,D.N (2004). "Semantic Web based services for intelligent mobile construction collaboration", ITcon Vol. 9, Special Issue Mobile Computing in Construction, pg. 367-379

Aziz,Z., Anumba,C.J., Ruikar,D., Carrillo, P. & Bouchlaghem, D. (2006) "Intelligent wireless Web services for construction—A review of the enabling technologies" Automation In Construction, Volume 15, Issue 2 , March 2006, Pages 113-123

Behzadan A. H., Aziz Z., Anumba C., and Kamat V. R. (2008), "Ubiquitous Location Tracking for Context Specific Information Delivery on Construction Sites", Automation in Construction, 17(6), Elsevier Science, New York, NY, 737-748.

Garza., I.M and Howitt., I. (1998), "Wireless Communication and Computing at the Construction Site", Automation in Construction, Intl. Journal for Construction Professionals, Elsevier Science, Vol. 7, No. 4, pp. 327-347.

Kondratova, I (2003) "Voice and Multimodal Access to AEC Project Information" The 10th ISPE International Conference on Concurrent Engineering: The Vision for Future Generations in Research and Applications. J. Cha et al, (eds), Swets & Zeitlinger. Lisse, Portugal. July 26-30, 2003. pp. 755-760. NRC 45829.

Menzel, K., Eisenblatter, K., Keller, M. & Scherer, R.J (2002) "Context-sensitive process and data management on mobile devices", *eWork and eBusiness in AEC*, Turk & Scherer (eds), Swets & Zietilinger, Lisse, pp. 627-634.

Pashtan, A (2005) "Mobile Web Services", Cambridge University Press, 2005. pp. 13, ISBN: 0-521-83049-4.