TOWARD ADAPTIVE CONTEXT-AWARE USER INTERFACES FOR BETTER USABILITY AND PRODUCTIVITY IN AEC COLLABORATIVE TASKS

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ABSTRACT

The Architecture, Engineering and Construction (AEC) sector gathers a wide range of stakeholders, roles and activities that may be performed in heterogeneous contexts. By "context", we mean not only the environment and user's particularities but also the "cooperation context" associated to the activity to be carried out. The activity in the AEC projects is highly collaborative, particularly uncertain and takes place in a continuously changing "cooperation context" (e.g. due to new plans, new stakeholders, problems on site, etc.). The activity is also characterized by a strong mobility (e.g. workers on the building site) that implies information availability issues. Therefore, we suggest in this paper to consider new potential of context-aware technologies to support AEC business tasks. Interactive systems proposed for the sector do not usually address the usability issues implied by the various context changes. So, this paper introduces the use of Adaptive User Interfaces (AUI) for the AEC activity. AUI are particular context-aware applications capable of adapting themselves relevantly to the current context in order to better fit the ongoing task and the users. For this purpose, it is firstly required to identify the particular AEC context properties and to characterize them. Based on a state of the art, we propose a highlight of the contextual information relative to the collaborative aspects. We then suggest reviewing AUI and focusing on their principles and capacity to improve visualization and interaction according to the user's task. Many technical approaches exist such as the Model-Driven Engineer methods which we cover through a state of the art of AUI systems. Finally, we identify the potential usability and productivity benefits to apply AUI to common AEC tasks. For instance, we consider throughout this article, the cases of construction site meeting and inspection reporting. These cases are good examples of context variability, both organizational and environmental.

Keywords: interface adaptation, context-awareness, collaborative work

1. INTRODUCTION

Nowadays, Human-Computer Interactions (HCI) are part of our everyday life. Users are now very mobile and constantly connected thanks to the proliferation of mobile devices. This new tendencies imply that users evolve in an ever changing context of use. This is particularly true in the Architecture, Engineering and Construction (AEC) sector where mobile devices are now accepted and used as supporting tools.

The AEC context is more complex than the average user's context. Collaboration is intensive, organization are quickly changing, the stakeholders have many different positions and capabilities and mobile devices are more and more in use to support the AEC activities.

Typical IT systems that support AEC tasks are commonly designed statically and only consider a unique context of use, thus lacking in versatility in supporting multiple contexts.

To address this problem, approaches do exist, such as the context-awareness approach. It promotes the detection of contextual information and to consider them for decision making. Context-aware systems are capable of proposing the right service for a situation. Furthermore, a particular category of context-aware system, the Adaptive User Interfaces (AUI) enable an interface to adapt its representation to better fit context changes.

Hence, it is interesting to characterize the specificities of the AEC context with the intention to use them for context-aware purposes. Designing tools with AUI features represents a possibility to enhance current AEC tools by providing more relevant information and features more suited to particular contexts.

In this paper, we take a look at what a context is and argue about the particularities of the AEC context. Then, follows the introduction of context-aware systems that help designing more versatile tools by considering the context's dynamicity. This leads us to a particular type of context-aware systems: the adaptive user interfaces. Such interfaces and their current application to the AEC are presented. Finally, we explore their possibilities by introducing a case study in the AEC context.

2. THE INS AND OUTS OF THE CONTEXT

2.1 What is a context?

Contexts are part of our very nature of thinking being. Humans constantly think and take decisions with context considerations, consciously and particularly unconsciously. Thinking with contexts feels natural to our brain. In general terms, the context represents the conditions, the circumstances and/or any connected things under which an event happens. But a context is, by definition, something subjective and depends on the activity or practical domain. For instance, in writing, a context defines the surroundings of a word or a sentence which imply a completely different meaning depending on the context. Hence, we could say that the definition of the context is itself context-sensitive.

For the purpose of this paper, we focus on the context definition regarding Computer Science, more specifically regarding HCI. In the HCI field, the context is the set of conditions under which an interaction is carried out. (Schilit et al. 1994; Schilit and Theimer 1994) are among the firsts to have defined a context relative to the HCI domain when they introduced for the first time "context-aware" computing. They have identified a context to be representative of *where you are*, *who you are with*, and *what resources are nearby* (including technical capabilities of those resources). This definition is restricted to the needs of their experiment (Schilit et al. 1994) thus not being a quite general approach of a context definition (e.g. this definition doesn't take in account environmental elements such as the luminosity). Another early notable definition is (Pascoe et al. 1998) one, defining a context as the physical body position of a user and his work pace. This definition is too much user centric while also not covering efficiently user profiles. The most largely approved context definition has been introduced by (Dey 2001). Based on (Schilit et al. 1994) and (Pascoe et al. 1998) works which he found to be too specific, he proposed a more generic and technically usable definition. He defines a context as follows:

> *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and application themselves."*

Following Dey's work, (Chen and Kotz 2000) characterize a context to be the combination of the following four sub-contexts:

- *Computing context*: On what devices the interaction is being carried out? What are their technical specifications? Screen sizes? Processing powers? Interaction modalities available? …
- *User's context*: Who is the user? What is his location? How old is he? What is his job position and current activity? Is he physically impaired? What is his emotional state? …
- *Physical context*: What's the weather like? How is the ambient noise? How is the lightning?
- *Time context*: Is our information semantically linked to the time? E.g. date and duration, consideration of past context instances to interpret the current context…

Dey's definition and the above characterization are well suited to context-aware application since they cover pretty well the user interaction sphere.

2.2 The specificities of the AEC context

The AEC context has specificities that goes behind HCI considerations of what a context is. In our previous work (Kubicki et al. 2006) we identified the strongest AEC particularities as being made of complex unpredictable type of organizations and an intensive cooperation. Hence, we highlight the following elements to be the most representative of the AEC context particularities:

- *Organization:* organizations in AEC are complex and of various types. Depending on the project phase, the stakeholders may be organized as a hierarchy, or as transversal organization. It is also common to face unpredictable types of organization due to problems arising or to the need to take quick decisions. This type of organization is made during the time span of the issue and people are self-organized. We are considering this type of organization as being ad-hoc. It principally relies on the ability, goodwill and autonomy of the stakeholders.
- *Collaboration:* the AEC sector regroups a wide range of stakeholders. These stakeholders have to collaborate with each other and this collaboration is often conducted on the field with ad-hoc organization (Kubicki 2006). Supporting tools are generally proposing static services, adapted to a precise type of collaboration and organization. A tool should consider the strong heterogeneity of the type of stakeholders (e.g. roles, tasks, capabilities …).
- *Mobility:* most AEC tasks imply a high mobility of the stakeholders. AEC situations are very varied and ask stakeholders to operate on many different settings (e.g. building site, commuting, office, visit at the owner…). The use of mobile devices is nowadays more and more accepted. Those devices have different hardware capabilities that applications have to deal with.

In order to use AEC contextual information, we found interesting to characterize and instantiate them regarding the definition of the context. Considering AEC aspects in HCI contexts may help to better understand the specific needs. Here we expand the notion of context to the AEC tasks:

- *Computing context:* due to the diversity in situations and in mobile devices, AEC stakeholders reside in a complex computing environment. They are continuously using and switching between devices such as laptop and desktop computers, mobile phones, organizers, tablets…
- *User's context:* most AEC particularities concern the user's context. Organization and collaborative tasks, stakeholders' roles and capabilities, heterogeneity of teams…
- *Physical context:* this type of context is the most straightforward. AEC implies potentially noisy and dusty environments. Temperature and weather also importantly act to understand some construction site happening.
- *Time context:* time is an important factor in AEC activity. The whole architectural project is integrated in a process from design to construction phases and exploitation of the building. Depending on the phase of a project, contextual information have different meanings and the stakeholders and the organization are not the same.

From this instantiation we showed that the AEC context is complex and dynamic. Designing supporting tools usually only consider a few static contexts, thus resulting in software not being adapted to many situations, especially when cooperation is involved.

3. THE CONTEXT-AWARENESS TO THE RESCUE

As previously noted, the context has many factors composing its instances. The problem is not restricted to the AEC sector and impacts, nowadays, any HCI. People are now connected everywhere, mobile devices are widely accepted and have radically different hardware capabilities. This propagation of electronic devices tends to complicate interaction paradigms leading to the loss of users' attention and to lower the productivity. In order to make the user focus on his task among a set of devices, new interaction paradigms came as a response, such as the "pervasive computing" (a.k.a. "ubiquitous computing" abbreviated "ubicomp").

3.1 Concept & history

Introduced for the first time by (Weiser 1991), the "pervasive computing" paradigm describes seamless interactions between the user and his surrounding electronic devices. The interaction is seamless to an extent that the devices' presence is omitted by the user. While "pervasive" and "ubiquitous" literally means "manifesting throughout everything", by speaking of *pervasiveness* or *ubiquity*, Weiser also refers to the transparent aspect of interactions. A way to achieve pervasive interactions is to tailor systems that are sensitive to the interaction's context. They react accordingly and propose adapted services to the user's task in a transparent manner. So called systems are known as "context-aware" systems and were firstly mentioned by (Schilit and Theimer 1994) while the authorship of the first application of such systems is commonly accorded to (Want et al. 1992), even though their application is limited to a location-awareness. Context-aware systems rely on the capture of contextual information (e.g. user's location and surroundings, time of the day, etc.) and on the system reactions depending on these information to better fit the user's needs or enhance the effectiveness of a system. Working with contexts enables to gather richer information that will unlock new processing possibilities without (or with less) user intervention.

Despite (Schilit and Theimer 1994) described a context-aware application as being able to "adapt [itself] according to its location of use, the collection of nearby people and objects, as well as changes to those objects over time", researches were mainly focusing on location as the only relevant contextual element (Abowd et al. 1997; Cheverst et al. 2000). Besides location-aware application, most researches were domain specific, limiting the usage of contextual information. It is only by the years 2000 that more elaborated definitions of what context-awareness is had showed up. (Schmidt et al. 1999) are among the firsts to have pointed out the limitation of location-aware system. Dey's definition (Dey 2001) is the one that united the domain's stakeholders and is stated as follow:

> *"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task."*

Context-aware systems are now commonly used in domains such as interfaces adaptation, smart environment (e.g. medicalized home), mobile advertisement (e.g. advertising dependent of your position), tour guide, etc. (Bolchini et al. 2007; Hong et al. 2009).

3.2 Adaptive User Interfaces

Adaptive User Interfaces (AUI) are particular context-aware systems that aims at generating user interfaces relevantly to the user's profile, task and environment (Coutaz et al. 2005). The AUI research domain comes from the crossover of the personalization domain (which consists in allowing the user to manually customize the interface) and the context-awareness. Hence, AUI focus on providing a user interface well suited to the user and its task with as less as possible user intervention. The main challenge for AUI is to design their mechanisms so that the usability is preserved.

Unlike standard context-aware systems, AUI promote a re-organization or a re-distribution of a user interface where context-aware systems associate a unique interface per service. On the detection of a new context, AUI may re-arrange the graphical components (and their properties such as the size), the available modalities or the type of visualization to better suit the new context. The quality of AUI depends on the relevancy of the adaptation considering the task and on the intrusiveness of the adaptation. An AUI that adapt too many times without the user's approbation may have a negative impact on the task.

AUI represent a complex problem addressed by particular approaches. A notable one is the "plasticity" approach which originally aimed at resolving interface adaptation problems considering an adaptation to the device (*computing context*) and to the physical environment (*physical context*) (Calvary et al. 2002). Plasticity employs a Model-Driven Engineering (MDE) tactic to design interface having multiple representations (one for each targeted context) and distributed interfaces (interfaces capable to display on several devices) (Coutaz et al. 2003). Plasticity design suggests that the contexts are known at design time. The concept evolved to consider the *user's context* and more recent researches on plasticity introduced the consideration of *time context* by using learning systems to depict users' preferences and habits (Ganneau et al. 2008). Plasticity focuses on modeling multi-target interfaces, distributed interfaces, physical environment, hardware and software capabilities and tasks.

The mechanism of adaptation is commonly dealt through Service Oriented Architecture (Coutaz et al. 2007) or component based approach (Demeure et al. 2008; Hariri et al. 2009).

Another approach to context-aware interfaces is the USer Interface eXtensible Markup Language (UsiXML) (Limbourg 2005). UsiXML is a user interface description language that aims at modeling relevant aspects of the interfaces to support context-aware application. For this purpose, UsiXML introduced the "µ7" concept (http://www.usixml.org/key-goals) which consists in the design of "multi-device, multi-platform, multi-user, multi-linguality / culturality, multi-organisation, multi-context and multi-modality"enabled interfaces. UsiXML models are partly based on the works on plasticity and propose models to enable the adaptation of the interfaces to the user's context.

3.3 Usage of AUI for AEC tasks

AUI are capable of providing better suited information and interfaces. AEC tools could benefit from AUI due to its complex setting. Typical AEC tools are designed to address a specific problem with no context consideration. This result in tools proposing static services that are not suited to all situations especially when it comes to mobility and on-site problems. Our hypothesis is that AUI could help designing tools that support a wider range of situations and promote cooperation. Such tools would be more usable and accepted, ultimately enhancing productivity and problem solving.

Considering the complexity of the AEC context and the wider use of mobile devices, researches on context-aware systems applied to the AEC sector have already been conducted.

Among the notable ones, Aziz's works (Aziz et al. 2006; Aziz et al. 2009) are based on the ascertainment that data in mobile context are usually statically presented. This does not fit to the AEC context where the conditions of a project are very dynamic. They propose to use context-aware systems to present context-relevant services and information. Their vision of relevant information is similar to the AUI definition and suggests showing data relevantly to the current context, role and task. They also suggest to use learning systems to profile user in order to personalize the interface and to use contextual information for safety warnings. Finally, they are exposing the idea to have interfaces capable of adapting themselves to backup devices such as mobile phones.

As of concrete applications, very few possibilities seem to have been done. We can mention (Eisenblätter et al. 2006) adaptive forms for errors & omissions management. They used a MDE approach to design electronic forms that adapt to the context. Their notion of context is limited to the skill of the user and the adaptation consists in proposing optimized forms accordingly to the user's skill for better productivity and acceptance. They also consider mobile phones and desktop computers as the targeted platforms, thus having multi-target models.

Existing applications (being AEC specific or targeting standard AUI) do not seem to consider the particularities of the AEC collaborative context and suggest applying context-aware systems to AEC tasks. Yet, models are extensible enough to cover the modelling and the use of collaboration, organization and mobility aspects in the context-aware process and interface adaptation. This lets us envision more elaborated applications for the AEC sector.

4. TOWARDS A CONTEXT-AWARE APPROACH USING AUI FOR AEC SERVICES

This section suggests considering an existing application developed at the CRP Henri Tudor, Build-IT "Meeting report" (intended for the writing and the exchange of building site meeting reports). This application does not feature any AUI capabilities. Our aim is to formulate context-aware prospects which could be of interest for using this application in various business situation (e.g. mobile, meetings etc.). This approach will allow us to illustrate the interest of a context-awareness approach using AUI for the AEC activity based on the study of a real application.

4.1 Build-IT "Meeting report"

The Build-IT "Meeting report" service has been developed in the framework of the research project Build-IT (2004-2009), which aimed to design and transfer IT services supporting coordination activity in the Luxembourgish AEC sector (Kubicki, et al. 2009). The building site meeting report is an important coordination

element in the AEC projects, this is why, one of the objective of the Build-IT project was to study the process around the writing and diffusion of this document. The study allowed us to highlight the collaborative best practices linked to the building site meeting reports and the composition of the document in diverse sections (i.e. information relating to the agenda, the presence, the remarks, the next meeting, etc.). Based on this analysis, we developed a Web-based application intended to assist the writing and the reading of meeting reports thanks to a standard structure based on composite elements. This application proposes functionalities to support the following practices (see Figure 1):

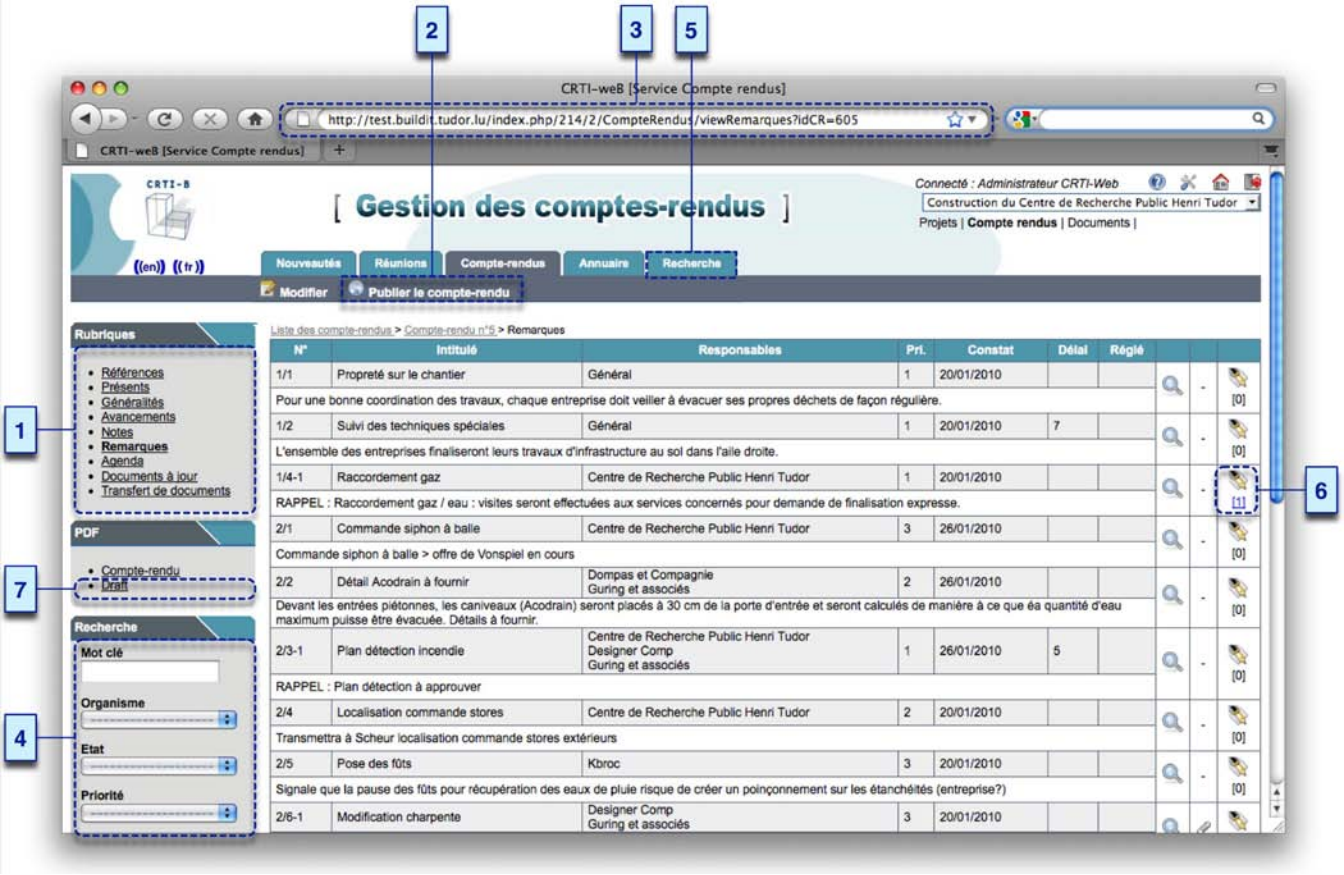

Figure 1. Build-IT "Meeting report" and supported best practices

1) Supporting the writing of the meeting reports by structuring data entry according to the sections of the document and by retrieving consistent data from the last report (i.e. opened remarks).
2) Rapidly and efficiently diffusing building site meeting reports to each concerned stakeholder.
3) Accessing at a distance and at any time to building site meeting reports by the Web application.
4) Dynamically consulting the content of the reports by navigating in the sections and filtering information exclusively dedicated to a stakeholder or another.
5) Searching elements inside building site meeting reports by keyword and by using diverse combinatorial filters (e.g. priority of the remarks, concerned building element, date, etc.).
6) Tracing the comment made on a remark by a reader (e.g. because the content of a remark requires more information).
7) Assisting the organization, and the sequence of the building site meeting by generating a well-spaced text making annotation easier, retrieving consistent data from the last report and integrating all reader's comments.

4.2 Experiment and transfer

This prototype has been experimented in the framework of 11 real construction projects performed by 4 architecture or engineering agencies. The user's interviews have allowed demonstrating that the tool is enough simple, reliable and requires just a few training to use it. The experiment has demonstrated that the tool is suitable for the professionals' daily work and that it allows the users to gain time in writing, and consulting the meeting reports. Nevertheless, the prototype has been also perceived as limited especially regarding the personalization of the generated document (i.e. meeting report in PDF). Finally, the users' feedback during the experiments enabled us to adjust the functionalities and to resolve bugs.

After this phase of experiments, an intensive phase of development for finalizing the Web application and the selection of a service provider, the application has been transferred to the Luxembourgish construction sector. The solution is now commercially available under the registered trademark "CRTI-weB®" (http://www.crti-web.lu/).

4.3 Context-aware prospects

The interviews and experiments have highlighted that the meeting report writing takes place in different contexts: firstly, in the building site (for the draft document) and secondly, at the agency, office, or eventually at home (for the final meeting report). The multiplicity of sites and manipulated information support and devices (paper, laptop, mobile, camera, etc.) is an important constraint for supporting the data entry in a system. The AUI approach could considerably improve the "meeting report" IT system presented in the section before. It could allow stakeholders to obtain the right information at the right time, to improve the data entry and promote better collaboration.

Therefore, we suggest considering the different contexts described in section 2 and formulating context-aware prospects using AUI for the construction meeting report management:

1) Computing context

Considering the "computing context", the device manipulated by the user may impose hardware restriction (e.g. adapting the interface to a light version for mobile, or tablet). The multi-devices interactions is another point for improvement of the current "meeting report" application. If this application is running on a dedicated system, the presence of stakeholders can be detected by the presence of other devices which belong to them (e.g. mobile). This could enable filtering, for example, the remarks of the building site meeting report according to the persons in presence and their respective roles. This could be done by AUI if we consider the detection of stakeholders' personal devices as a change in the computing context. AUI also allow to omit interface parts on purpose in order to correctly display data on mobile devices. It is also possible to take advantage of interaction modalities that are not available on desktop computers (e.g. accelerometer, touchscreen, etc.).

2) User context

Considering the "user context", the views manipulated by a specific user could be adjusted according to the role that he/she plays in the construction project (e.g. architect, engineer, owner, contractor, etc.), his/her preferences, or the activity that he/she has to perform, etc. Projects in AEC have the particularity to be collaborative. The tasks performed by the multiple stakeholders are finely interconnected (i.e. the output of a stakeholder is needed as input for another one). In the traditional context-aware approach, the user's task is considered as independent of the collective activity. It could be interesting to adapt the views, or services in function of the state of the collective activity in order to improve the perception of the situation. For example, the application could present a view that is suitable to all the stakeholders and also consider their own preferences and context. The application could also inform the user that a new meeting report is published and that there are three urgent remarks concerning him/her. After that, some particular services could be recommended according to the content of the remarks, his/her role and current task (e.g. recommendation of the planning if the remarks concerns a delayed task).

3) Environment context

The activity related to the meeting report management is performed in multiple places (e.g. architecture agency, building site, etc.). These places have different characteristics (e.g. temperature, localization, noise, etc) that could

impact the services (or functionalities) recommendation. Different prospects could be imagined in the point of view of the environment context. For example, the data entry of the remarks could be made on site during the visit and the assessment of the progress. The remarks could be therefore associated to a precise building element localized in the building (e.g. by RFID technology) in a transparent manner. They could also be filtered during the visit according to the localization of the user in the building. It is important to consider that on the building site, the environment can be very noisy. The device could take into account that, in this case, some functionalities are not adapted and, consequently, they do not have to be recommended in situation (e.g. recording vocal remarks not available if the environment is noisy). The device could also identify temperature on site and automatically introduce the value in the meeting report for justifying that the temperature on site do not allow the execution of certain building elements.

4) Time context

The "time context" allows us to envisage some prospects related to the context history. That could be interesting to identify the user's preferences by observation of his/her behavior. For example, if the user systematically consults the meeting reports each Monday at 9.00, it could be automatically recommended to open the meeting report application at that time. Finally, the context history opens interesting prospects to reuse solutions solving problems on other building sites in similar situations.

These diverse prospects allow us to identify the interest of AUI in the AEC activity and more specifically for the meeting reports management due to the intrinsic nature of the activity performed on different sites, in a collaborative context. Currently, some developments are under progress to improve the data entry during the building site visit, and to integrate some aspects related to the localization.

5. ONGOING WORK ON AUI FOR AEC TASKS

Our current effort is focused on the appropriation of AUI researches and technologies. As exposed, AUI offer opportunities to withstand the complexity of the AEC context. We made the choice to further explore the MDE plasticity approach because of its maturity, its extensibility and the availability of usable frameworks (e.g. the CAMELEON one; see http://giove.isti.cnr.it/projects/cameleon.html). These frameworks allow to design multi-platform applications capable to adapt their representation according to the user and his/her task.

If the mentioned mobility issues can be easily dealt by current plasticity frameworks, collaborative aspects are still to be considered. Collaboration and AUI raise the problem of consistency in adaptation: two stakeholders in two different contexts may have different representations, thus having difficulties to collaborate. The main challenge in proposing AUI for collaborative tasks is to address this problem. Our objective is to add collaboration support to plasticity framework by creating meta-models of collaboration based on existing works (Halin & Kubicki 2005). A focus on consistency will be made by integrating usability aspects based on *What You See Is What I See* (Stefik et al. 1987) and *Common Ground* (Clark 1996) recommendations (and will have to be present in our collaboration models).

This has led us to the prototyping of a context-aware mobile application that will help to validate our proposition and serve as a backbone for future developments. This application is based on Build-IT "Meeting report" and consists in a mobile version of the tool (Schwartz et al. 2010). The goal is to implement the above mentioned prospects in this application. AUI capabilities are still to be conceived in this prototype. The resulting application will be tested on the field to validate our prospects and measure the impact of AUI on AEC collaborative tasks. The test protocol and the exact tasks aimed are yet to be identified.

6. PERSPECTIVES AND CONCLUSION

Context-aware systems, and more specifically AUI, offer new opportunities in terms of interactivity for the AEC tools. To this purpose, we introduced the notion of context relative to the HCI research domain and exposed the fact that the AEC context is more complex. It is a highly collaborative context, having multiple and unpredictable

organization issues. We also noted the wider use of mobile devices in the AEC activity and the heterogeneity of the stakeholders' roles.

To take the most out of the complex AEC context, we presented the context-aware computing which promotes the use of contextual information act relevantly to the user's context and task. Then followed a look at AUI, a specific type of context-aware system which better corresponds to our goal to enhance the usability and versatility of the interface of the AEC tools.

Through a case study of the Build-IT "Meeting report" service, we highlighted that AUI could benefit to many aspects of an AEC tool. AUI may help designing tools capable to adapt themselves to collaboration context where different stakeholders interact. The mobility and the diversity in mobile and non-mobile devices may also be addressed with a single adaptive interface capable to adapt to the device and harsh situations such as building site. The consideration of a time context could also enable the profiling of the users' behaviors and help AUI proposing re-modeled interfaces that better suit the personal habits of the users.

In our future works, we plan to contribute to the MDE approach at representing contexts by adding the particularities of the AEC context we have identified. This work is mandatory to concretize the envisioned enhancements of the AEC tools. For instance, we are currently working on an AUI framework for mobile devices and planning to apply the result to our AEC tool.

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