Using Customized Navigational Models to Deliver more Efficient Interaction with Mobile Computing Devices on Construction Sites

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Abstract
Mobile computing devices have started to become useful tools on construction sites. These devices can make large amounts of data available and support data collection tasks on a construction site. Even though battery life, computing power and data storage capacity have greatly improved and will probably not be limiting factors for mobile computing solutions, it is still difficult to interact with mobile computing devices efficiently. Some of the factors limiting efficient interaction are the size of the screen of a mobile computing device, the deficiency of a keyboard and the limited accuracy of the pointing device. The approach we pursue is to limit the interaction needed for specific tasks that are carried out using a mobile computing device. To do this we are working on developing *Navigational Models*, which reduce navigation through large data sets by grouping data entities closely together, according to the need to be accessed for a specific task. Moreover, *Navigational Models* appear to be a useful construct to enter and access data at the right level of detail, which they needed. In this paper, we discuss the need for more efficient interaction with mobile computing devices on construction sites and introduce *Navigational Models*.

KEYWORDS: Construction, Human Computer Interaction, Mobile Computing, Navigation through Complex Data Structures, Product and Process Models

1 Introduction

Many documents available at a site office, e.g. drawings, specifications and schedules, are also needed on a construction site. Currently, for the "last mile" of the flow of information from the site office to the job site, computer-based documents do not work very well. In a majority of the cases, the information stored within an electronic document, or a product and process model, needs to be printed out to access it on the construction site.

Oftentimes, paper documents used on a construction site are not in a format appropriate for the environment in which they need to be used. Drawings and schedules may be too large to be carried to the locations where they are needed, and bills of quantities can amount to several hundred pages. As a result, site superintendents may not have the data with them at the time when they need the information. This deficiency leads to time-consuming document preparation processes to make data available on a site, and additional data transition processes to reintegrate data that has been acquired on a site into electronic documents.

In recent years, technologies that can bring computing power to a construction site have emerged. Mobile and wearable computers are powerful portable devices that can be used on construction sites. Moreover, Personal Digital Assistants (PDAs) and pocket computers have become popular because of their portability. Information contained in electronic documents becomes accessible right on a construction site when these devices are used. Observations that are made on a construction site can be integrated into electronic documents or models without having to make notes and to enter the information contained in the notes after being back in the office. Current mobile computing solutions for project management tasks in construction projects still have limitations. These solutions limit the complexity of the data with which the user is able to interact efficiently. Unless mobile computing devices for construction sites can bring all information to the construction site – both complex and not so complex information – and provide an environment within which a user can interact with the data efficiently, problematic paper-based solutions will continue to be used as the best available approach.

2 Current solutions

Many vendors of established IT solutions for construction processes, such as Primavera, AutoDesk and Meridian, provide mobile clients for their main product, e.g., Primavera OnTrack, AutoDesk OnSite, Meridian Prolog Pocket, respectively. The client applications are equipped with functionalities needed on a construction site in order to access and collect data for a given application.

The information we acquired from site superintendents, who have been using a commercially available mobile project management solution, suggests it has been hard for them to enter textual data on the construction site in an efficient way. For example, the specification of the location of a problem requires cumbersome selections from long lists of location descriptions. If the list of possible locations was kept shorter they were not able to specify the location at the desired level of detail. A similar selection problem was identified for the input of the problem description. Even though the considered application handled relatively simple data sets, the interaction with the device and the application was challenging, as the site superintendents had to trade off between an accurate description of the problem and efficient data input. Case studies carried out by another research group corroborate our observations that current mobile computing solutions fail to make complex data sets available to the user efficiently (Dogan et al 2001).

3 Related work

There appear to be three areas that are relevant for research addressing the problems stated in the previous section: a) information and data collection needs for knowledge based tasks on construction sites, b) Human Computer Interaction (HCI) methods for interaction with large data sets and mobile computing devices, and c) data models that provide the information needed on the construction site.

Obviously, there are a number of knowledge-based tasks that are needed on construction sites, which may vary among projects, but trades also may vary within one project as the project advances. The published literature does not provide much information that explicitly states knowledge-based processes and data needs on construction sites. Nevertheless, there are a number of implicit statements that information is needed on construction sites and office-based processes require information, which needs to be collected on the construction site (Dogan et al 2001, Pena-Mora, Park 2001; Mills 1999, Tommelein 1998). These statements motivate our research to make the data needed accessible in an efficient way.

For an efficient navigation through large data sets, Furnas (1986) has identified that tree structures are especially beneficial, as they allow the user to interact with the data on different levels of detail and access detail and context information at the same time. Chien and Flemming (2002) propose tree data structures for efficient navigation through large design spaces in architectural design and Bjoerk (1999) states that rich linkage between semantically related entities in a large data set enhances the efficiency of information access (Bjoerk 1999; Chien and

Flemming 2002). These techniques for efficient navigation through large data sets are relevant for our research as the sources of data that may be needed on a construction site can be large (construction projects may have several hundred drawings and thousands of pages of specifications).

Even though product and process modeling originated from design rather than construction problems, researchers have shown the usefulness of product and process models for the construction phase of buildings. There have been proposed product and process models that specifically address processes in the construction phase of a building (e.g., Stumpf 1996, Akinci 2000, Froese et al 1999). These product and process models appear to be the way of handling and storing construction related data in the future and should therefore be the model that contains the data that we want to make available on a construction site.

4 Making data accessible on site

In our research, we hypothesize that allowing interaction with data presented to the user on variable levels of detail (LoD) will enhance the efficiency of user interaction. Moreover, we hypothesize that linking semantically related information and presenting the links to the user minimizes navigation needs during interaction with an integrated product and process model that handles the information needed on a construction site.

4.1 The level of detail problem

In a case study with a mobile computing application, we experienced that the level of detail at which data is presented to the user and in which the user enters data in a mobile computing system has a significant effect on the efficiency of the interaction. This experience is consistent with another case study that investigated the usefulness of an Augmented Reality (AR) System for inspection tasks in Nuclear Power Plants (Dutoit et al. 2001).

For construction projects, many information access and data collection tasks can be seen as problems related to the level of detail. We identified punch list creation, punch list maintenance and construction progress monitoring as knowledge-based tasks that are carried out at construction sites and require interaction with data at different levels of detail. For example, the question about what the punch list items of the project are needed to be resolved in the following two weeks may relate to the overall project, a section of the project, a certain room, a trade or a certain contractor. For progress monitoring, the user needs to enter the observed construction progress in a mobile computing device. The observed construction progress may need to be considered at different levels of detail, such as the building element level, the activity level or a higher-level grouping of activities.

Interaction with the computing device becomes inefficient or ineffective if there is a mismatch between the level of detail, in which the user is interested or the user wants to enter data, and the level of detail provided by the application. For the progress monitoring application we tested, (Reinhardt 2000), the level of detail for the construction progress was the building element level (e.g, "installation of wall 3 on the 3rd floor is 50% complete"). This high level of detail was appropriate for tracking closely the work of subcontractors, who were constantly late, but for other less problematic activities, the level of detail was too high. The site superintendent had to enter the construction progress of all building elements of one activity even though the actual information she wanted to enter was that all other activities of a certain trade were complete (lower level of detail). The number of clicks on the touch screen of a mobile computer to enter the observed construction progress at the building element level rather than, for instance, at the activity level was typically around 3*n times higher, where n is the number of building elements associated with an activity (it takes 3 clicks to update an activity that is assigned to a building element). In the case study, n was typically in a range of 3 to 4. For progress monitoring, we could show that the level of detail in which the user interacts with a mobile computing application has a significant effect on the cycles of interaction needed for a particular task.

4.2 Minimizing navigation needs

Considering the objective to make all information needed on a construction site available through a mobile computing device, it is obvious that large amounts of data are involved. We assume product and process models to be the knowledge base for construction projects in the future. Even though these models integrate information and hence make the contained information available to the user in a unified way, the navigation across data domains can become very extensive. For this reason, efficient navigation through the data is crucial for efficient interaction with the mobile computing application. In order to reduce the cycles of interaction needed for a particular navigation task, it appears desirable to link information items that are semantically related. Product and process models may already have a rich set of semantic links between the information items included in the model. In the personal organizer application PowerView, researchers have linked semantically related items and presented these links as context information to the user (Bjoerk et al 2001). For our research, we want to build on Bjoerk's approach of linking semantically related objects together and investigate its usefulness for the computer supported knowledge-based tasks on construction sites.

5 Example envisioned interaction style

The task is to determine the degree of completion of the installation of windows at the building element level. When the last update of the construction progress was done, the windows on the east side were completed 30% and no windows were installed on the other sides of the building. The current situation on the project for this illustrative example is assumed to be as follows: on the south side of the building, three windows have been installed, whereas the east side is already completed; the work on the two other sides has not started yet.

In order to record the current progress situation, the user needs to capture the changes in construction progress since the last site visit. The product model is organized in a given decomposition hierarchy as it is depicted in Figure 1.

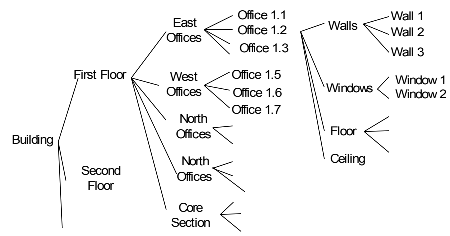

Figure 1, Representation of the data contained in a product and process model

As the user performs update operations only on windows, he/she specifies that a tree structure needs to be derived that only contains information related to windows (see Figure 2). The user also specifies that he/she wants to inspect the windows from outside the building and hence needs, for instance, a tree structure that groups windows at a higher level by the direction of the façade.

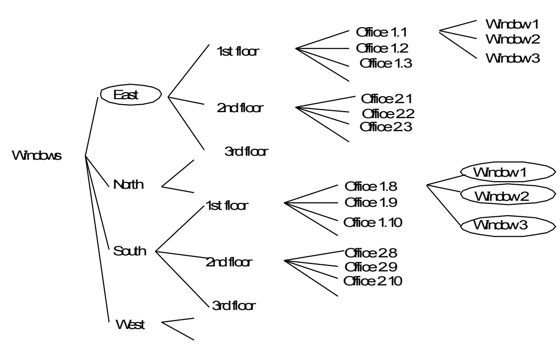

Figure 2, *Navigational Model*, Nodes (in circles) that need to be selected for the progress update

In order to record the progress update for the window installation, the user would select the node **East** (higher level) and classify all building elements on the east-facade as installed. For the south façade the user needs to select the items **Window1**, **Window2**, **Window3** (lower level) and classify the windows as complete. For the south façade, the information that needed to be entered was more detailed and hence the interaction with the system was more detailed compared to the interaction needed to enter the information related to the east façade. The proposed interaction style allows capturing data in a very detailed way, but requires less interaction with the data compared to solutions that present at a static level of detail.

6 Customized *Navigational Models*

Considering the opportunities discussed in the previous sections, we propose a system that supports efficient navigation through large data sets contained in integrated product and process models, which are presented on mobile computing devices. To achieve this, we propose *Navigational Models,* which are constructs that fulfill the following three conditions: a) establish links between information items in product and process models that need to be accessed on the construction site, b) support interaction with data sets on different levels of detail, and c) do not contain information, but rather contain references to information items in a product and process model. Even though linkages between entities may already exist in product and process models, additional linkages or direct linkages specific for a task may become necessary. One representation of a *Navigational Model* is a tree structure, which has leaf nodes that have references to data in a product and process model. The data at the leaves of the tree structure have to have the highest granularity of information in which a user might possibly be interested. Higher-level tree nodes are dynamic aggregations of lower-level nodes and do not have their own attributes other than references to parent or child nodes. However, all data related to the leaf nodes can be made available in non-leaf nodes due to the child-parent associations between the nodes.

One version of the *Navigational Model* supports interaction with data at different levels of detail, as higher-level tree nodes represent data aggregations of lower level data and hence are less specialized. The user is expected to interact with the tree nodes that represent the desired level of detail. In addition to the tree structure representation of a *Navigational Model*, these models should be editable and changeable. The user of the envisioned system should be able to change the configuration of nodes in the model and thus customize the proximity of nodes in the model. The ability to customize a *Navigational Model* responds to the requirement to link information that is semantically related.

The customization of a *Navigational Model* is a means to reduce the navigation space for a given task. In contrast to views of a model, a *Navigational Model* is a construct that specifically supports a task by providing information needed for the task. Views are rather isolated representations of data contained in a model and may not support tasks, as tasks may require efficient interaction with different views. A *Navigational Model* is a task-centered interaction scheme that provides the user with information in representations that are appropriate for the task and the environment of the user. Different from views *Navigational Models* establish linkages between information items contained on product and process models. *Navigational Models* should enhance both information access and data collection on construction sites.

6 Conclusion and future work

Mobile computing devices can support knowledge-based processes in mobile environments and have started to become useful tools on construction sites. These devices can make possible more efficient and consistent data handling during the construction phase. Computing power and future network connectivity will not be limiting factors to make all data needed on a construction site available on electronic devices. Interaction with mobile computing devices is a major limitation for a wider usage of these devices.

Current interaction styles with mobile computing devices and applications often do not consider domain knowledge in order to enhance the efficiency of the interaction with the device. For the domain of project management during the construction phase, we have shown that incorporation of domain knowledge can enhance the interaction with mobile computing devices. Based on these considerations, we have proposed *Navigational Models* that incorporate domain knowledge of the task a user is doing on a construction site. The proposed *Navigational Models* are envisioned to enhance the efficiency of mobile computing applications in two ways: a) allowing interaction with information contained in a product and process model at different levels of detail; and b) link closely together that information upon which the user is likely to execute operations.

This paper has motivated the need for *Navigational Models* by describing the problems users have with levels of detail and navigations through large data sets. We also described the basic functions of such a model and discussed several ways in which these *Navigational Models* might enhance the efficiency of interaction with mobile computing solutions. Future work will implement and test this concept further.

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