Real time construction progress control using NFC

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Abstract

The verification of progress information is important for managing building projects. More often than not, this information is not available in real time. This paper describes both the concept and the implementation of how to collect data on a construction site at the point of happening and make it available for those involved in the project on a central platform in real time, using the NFC technology.

1 Today's management of progress information

In large, and accordingly somewhat complex construction projects in particular, the verification of progress information is important for the actual operation a building project. Unfortunately, this information is not available in real time. More often than not, a paper-based form is filled out, faxed and then manually typed into an electronic data processing system. This process is naturally very time-consuming. In fact, processed progress data, such as the completion of a lot of information about omissions, cannot be considered as actual data. Electronic daily construction records dispense with paper yet fail to provide real-time information, since these systems are not normally connected to a back-end system. Moreover, there is still the risk of entering incorrect information into the system. Despite the use of electronic builders logs it is still possible to mistake the identification of one part with another and so provide misleading feedback to the project management.

2 Problems and challenges in construction projects

Unforeseen events often occur on construction sites and numerous events cause delays. Accurate information on the building process is required to trigger early countermeasures and to avoid costly delays in the construction process.

Nowadays, the documentation of the construction process usually takes the form of written records which are filed in folders on the construction site or at the companies. This kind of information management is time-consuming, because the required data has to be found and taken out of the folders or needs to be copied manually into the information system. Typing errors easily occur data get lost because notes were illegible or labels have completely disappeared, making it impossible to compare the actual status with the target performance. Even if the so-called "actual" data is finally transferred into a back-end system it is already out-of-date. So it is not possible to respond quickly to a problem when it arises, leading to delays in the building process and making the controlling and scheduling of construction projects unnecessarily complicated.

In addition, the accounting of work is late (one to two months on average). Work that is carried out on an irregular basis is not billed because of lost data. This can result in a financial risk for small and medium-sized companies in particular, but even big companies lose money because of the belated invoicing.

In view of these problems, a concept has been developed that permits a real-time construction progress control by combining modern identification technology with a contemporary data management system.

3 State-of-the-art data acquisition and up-to-date data provision

The following section discusses different ways of collecting progress data on a construction site as well as examining the transmission of this information to back-end IT systems.

3.1 Technologies to capture actual data on construction sites

To achieve an effective construction progress control, a simple, automated retrieval system for actual data is required. Every component or resource accordingly needs to be given its own unique ID. There are several different identification technologies that can be used for this purpose.

The easiest and most popular identification method in the construction industry is the engraving or stamping of numbers. The advantage of this method is that no special equipment is required to apply or read the number. Furthermore, this kind of marking is resistant to dirt and climatic conditions, two basic requirements for every marking method. The disadvantage of the method is poor automation of the reading and identification process and the resultant manual effort involved.

The application of barcodes, clearly legible writing or company labels are alternative marking options. This method is cost-efficient, easy to attach and to retrieve. The use of barcode labels makes the identification process. automatable. The possibilities of data manipulation and its sensitivity to dirt and damage are the handicaps of the method.

The RFID technology makes it possible to identify the component parts of all kinds of equipment through the housing without any need to dismantle assembled systems. For instance, an RFID transponder can be placed inside an element or sub-assembly, provided it is not made of metal, in order to protect it against environmental conditions. The RFID identification process lends itself to automation. Compared with other available methods, RF-ID technology is more expensive. The environment of the construction site with lots of metallic objects can have a negative influence on RFID but a lot of progress has been made during the past few years in the development of RF-ID systems, so the RFID technology is now mature enough for practical implementation in the construction industry [11].
The Near Field Communication (NFC) technology represents a special, upgraded version of RFID technology and has the advantage that information can be read through materials, like standard RFID, but with a shorter reading distance. NFC technology is currently designed primarily for use with mobile phones, such as the Nokia 6212 or 6218 [13]. These devices are developed for the down-market and suitably low-priced. In addition, workers are accustomed to using mobile phones so they are spared the necessity of learning how to use a new technical device, which makes the system more acceptable [12].

3.2 Data handling in back-end software

Data not only needs to be captured, but also provided to all participants in a construction project in order to enhance results. A digital builder's log, containing all the relevant data concerning the construction site, could be a feasible solution for storing progress information. But, more often than not, these systems are isolated applications which are not connected to the back-end data management systems. Hence, the best solution is to store the progress information directly in the system, where all the construction data is stored and managed centrally. The following figure presents an overview of suitable solutions for the construction industry.

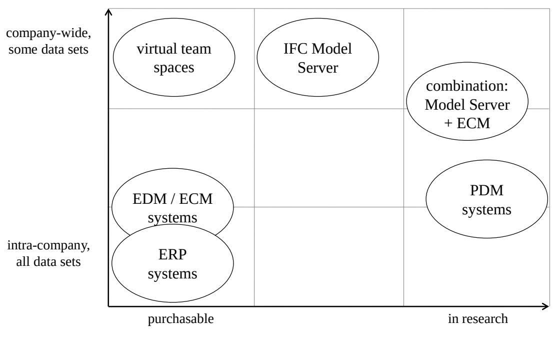

Figure 1 Data management solutions for the construction industry

Enterprise Resource Planning- (ERP) and Electronic Document or Enterprise Content Management (EDM/ECM) systems are well established both in the construction and the stationary industry [1], [2]. While ERP systems such as SAP R/3 mainly handle business procedures, EDM/ECM systems like DocuWare manage all documents generated by a company. More often than not companies run either ERP or EDM/ECM systems, the relevant information for both systems being exchanged via an interface provided by the vendors. These software solutions are restricted to use within the company – in a construction project, however, there are lots of different firms cooperating with each other to complete a building. All the players involved, such as the property developer, the architect in charge, the planner and the contractors should be able to access the relevant information concerning the progress of the project. In addition, neither the ERP nor the EDM/ECM systems provide a storage facility where the product model and accordingly the parts form the main focus.

By contrast, web-based, virtual team spaces such as 'baulogis thinkproject!' [3] provide an easy to use company-wide document management functionality. Special construction modules including:

- repro-service
- calendar
- defect management or
- an integrated builder's log

provide a convenient answer to today's problems regarding the documents accompanying building developments [4], [5]. However, this solution still does not provide a product model-oriented function.

IFC model servers do, in fact, support this feature, although they do not usually facilitate the management and attachment of all other documents like special requirements or quality-related documents [6]. Corresponding efforts to link IFC model servers and document management systems are currently undergoing research [7], [8].

Another approach to managing all the data arising in a construction project is being investigated by the German research corporation ForBAU. Product Data Management (PDM) systems, originally deployed in the stationary and automotive industry form the basis of the concept. These PDM systems are document management systems specialized in handling engineering data. This particularly applies to 3D models created by CAD applications. They not only provide the part-oriented functions required for linking parts, corresponding 3D models and drawings but also any other documents in a clearly arranged pattern. In addition, they provide a rights management system that makes it possible to assign roles to individual users. These roles in turn define the rights to read, write or lock individual files [9]. Apart from the fact that PDM systems are designed to serve the in-house information management procedures, which makes customization quite challenging, they seem to be an appropriate solution for the company-wide construction progress information management [10].

4 A concept for construction progress control

There are already various methods for collecting actual data from the construction site. Moreover, there are many software solutions for construction data management. But so far there is no solution available for automatically linking and allocating actual data from the construction site to the virtual data in the back-end system.
Following the best-of-breed approach, a concept has been developed which combines the best evaluated solutions for both data management and data retrieval (cf. 3.1. and 3.2.) to generate a total system for construction progress control in real time. Figure 3 illustrates the concept concerned.
The requirements of the system were defined in workshops organized for experts:

- The identification method has to be resistant to the rough environmental conditions.
- The identification devices for the construction site (including both software and hardware) must be easy to operate and must simplify the previous work process. If either of these requirements is not fulfilled, the system will not be used in the construction industry. In addition, the system needs to have an online and an offline mode, because it cannot be assumed that a mobile network is always available. Furthermore a way of collecting data in the form of text, images and voice messages is required.
- The back-end system has to represent the actual construction process at all times. To implement this requirement, the system needs to function on a part-oriented basis, so that every single component possesses an explicit ID, to which additional information can be attached.

To ensure the concept is up to standard, it was developed as follows:
An NFC mobile phone is used to capture the actual data on the construction site. This technology was chosen because it combines the advantages of RFID technology with the benefit of an easy-to-use and universally accepted mobile device. A PDM system serves as a central information platform.
To facilitate construction progress control, precast elements are labeled with NFC tags. Every component has a unique ID which correlates with the ID of the virtual component in the PDM system. The components on the construction site are identified with the help of the NFC mobile phone. By using a special software application, it is possible to attach additional data such as images, voice messages or comments for informative purposes and bundle them in an xml-file. This file is sent to the PDM system, where it is added to the virtual component record, and the status of the component is updated, for instance from "delivered" to "assembled". In this way, the construction progress is documented and up-to-date at all times, which in turn allows for an efficient construction progress control.

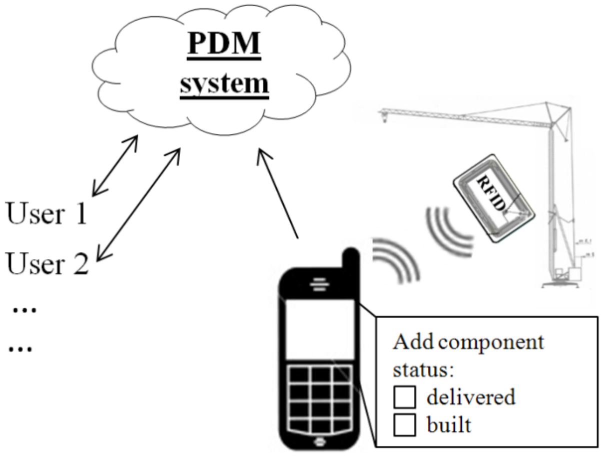

Figure 2 Concept of the construction progress control system

5 Implementation

The following paragraph describes how the concept specified in Section 4 is finally realized. First, the data has to be captured by software installed on a mobile device. The retrieved information then needs to be transmitted and incorporated into the PDM system.

5.1 Development of a software application using the NFC technology

A software application (mBDE – 'mobile Baudatenerfassung') for the mobile phone was developed to implement the requirements set out in Section 4. The two modes of use were defined in a workshop for experts.

Scenario 1
Precast elements arrive at the construction site. Each element is labeled with an NFC-tag containing a unique ID. The arrival of the elements is recorded by the foreman by identifying every element using the mobile phone. The identification process starts by approaching closely to the element. The NFC reader of the mobile phone detects the tag and the mBDE starts. After identification, the foremen enters the actual status "delivered" and can add further details, such as a description of the condition of the element. If the unit concerned is defective, he can take a photo of the damage and add a comment. He can also describe the damage by means of a voice message. Finally, he can send the information via GPRS, like a text message, to the PDM system.

Scenario 2
The precast elements are assembled. The foreman controls the work by identifying the elements using the mobile phone. He changes the status of the element to "assembled". If he encounters any damage or fault, he documents it by describing it with the mBDE by means of a comment, a picture or voice message (see scenario 1). Finally, the information is sent to the PDM system. If there is no network available, he can store the information and send it later.

The mBDE-software, which covers the modes of use mentioned above is implemented in JavaME. As soon as a tag is detected, the first dialog automatically appears. The tag ID is displayed and the user is asked if he wants to enter information. If the user confirms this, he can select the status of the component (“delivered” or “assembled”) and attach a comment. Then the user is asked if there are any defects.
If a defect is detected, the user can describe it by entering a comment. In addition, a voice message can be added. After recording the message, the user can choose whether he would like to save or delete the message. Then he can take a picture and send the information in the same way as an SMS. All the added information is bundled in an xml-file. This xml-file is sent to a web server via UMTS/GPRS. Figure 4 shows a sample of the mobile software.

Figure 3 Demonstrator mBDE

5.2 Linking the information from the mobile phone to the back-end system

After the software on the mobile device has retrieved and sent the required data, all the information, i.e. the completion of a lot, needs to be transferred to the back-end system and accordingly be forwarded to all those participating in the construction project. In the ForBAU project PDM systems function as the central information platform. As described in Section 3, an advantage of these systems is the part-oriented data management function, which means that every single part or sub-assembly is represented in a tree structure. Hence, every component can be seen as a node with an explicit ID, where all the required information is attached. Consequently, a part ‘abutment’ of an assembly ‘bridge’ would consist of object parameters such as ‘material=reinforced concrete’ and contain datasets like the 3D CAD model, the formwork drawing, special requirements or quality-related documents such as the paperwork of the flow diameter test. It is also relevant that every single part or rather node has a certain status, representing its maturity.

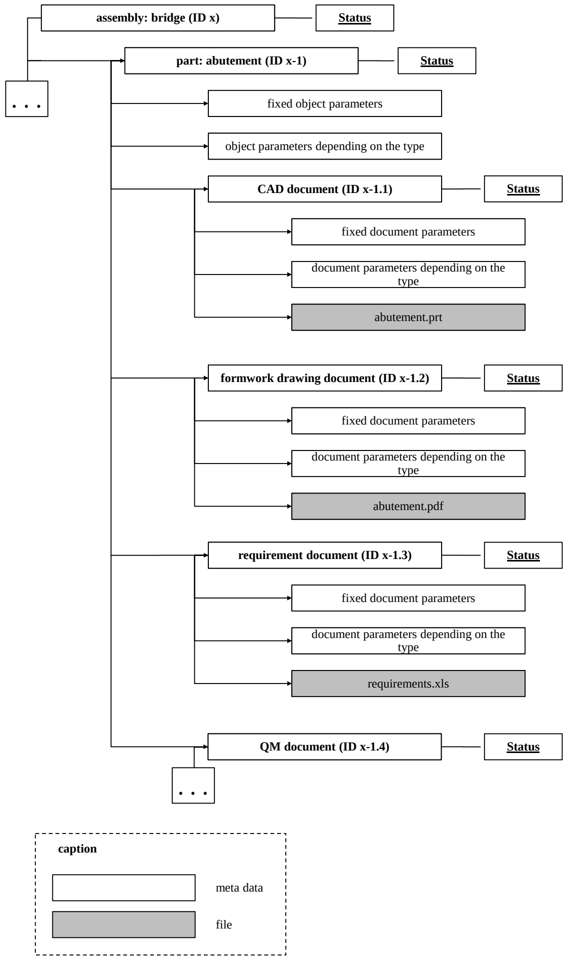

Figure 4 Ontology of a PDM system customized and enhanced for the construction industry [10]

As described above, the link between the virtual model and the physical building is realized using the same ID both on the real part’s NFC tag and the digital part in the PDM system.

As soon as the progress information is sent by the mobile phone as a single xml-file via GPRS/UMTS to a write/read released folder of a web server, it is necessary to ensure that the PDM server can access it. Once a new file appears in the folder, the xml-file is converted into zip file containing

1. a file consisting of the user-ID (User.xml)
2. a file containing the current status (Status.xml) of the physical object
3. optional:
   a) a jpg-file including a picture of the physical part
   b) a file with a description of possible scarcities or damages (Mangel.xml)
   c) a voice memo (Sprachmemo.mp3)

and moved to another folder, which is screened by a sender software. Every time new zip files arrive, the sender passes the file to a receiver applet that starts an algorithm to transmit the data to the right location inside the

PDM-environment. This algorithm can be described as following:

1. Parse the file name of the zip file, which is identical with the number on the NFC tag, but also with the ID of the virtual model of the part inside the PDM environment
2. Search for the corresponding virtual model in the PDM system
3. Revise the part, its attributes and datasets
4. Identify the person who sent the progress information by reading out the call number in the 'User.xml'-file
5. Check in the files containing the
    a. picture of the lot/part
    b. omissions and damages
    c. speech-memo

    to the PDM system
6. Link the checked-in files with the revised part and attach the person who sent the information
7. Parse the 'Status.xml' and change the status of the part
8. Write-protect the part in order to prevent further manual changes

The aforementioned algorithm was implemented in the PDM system Teamcenter 8, courtesy of Siemens PLM. Apache Tomcat 6 was used as a web server. A screenshot of the PDM environment illustrates how the information sent by the mobile phone is attached to a part, in this case a precast concrete element for the superstructure of a bridge. The status has changed from 'delivered' to 'assembled' (see figure 5; 'Eingebaut' = 'assembled').

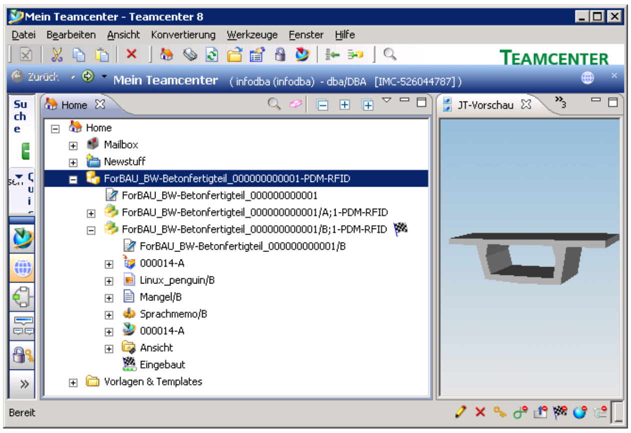

Figure 5 Implementation of the concept in Siemens Teamcenter 8

6 Conclusion

In construction projects, actual data from the construction site is not available in real time. Thus counter measures to offset unforeseen events are not triggered until it is fairly late, leading to costly delays in the construction project. It is for this reason that a concept for a real time construction progress control has been developed. An important goal was to make the progress data available to all the participants involved. Different feasible technologies to solve the problem were scanned and benchmarked. The final step was to chose the NFC technology for data retrieval and the PDM system for the centralized storage of the data. The concept was implemented and tested using a nokia NFC mobile device and Siemens Teamcenter 8.

Preliminary workshops were held with the company epocket from Norway in order to transfer the demonstrator program to a standard software solution.

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