

ForBAU – model-based management of infrastructure projects

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ABSTRACT: *The declared aim of the "Virtual building site – ForBAU" research project was to create a digital site model from the planning to the execution phase through to the LifeCycle perspective. The purpose of ForBAU was not only the three dimensional modeling of the structure, but also of the ground and the terrain. To enable the planning of a complete model, the mentioned submodels must be brought together. The challenge was that the individual models are created with different, highly specialized applications. Against this backdrop, interfaces and tools have been designed for the specific purpose of linking diverse tried-and-tested insular software solutions to form a single, comprehensive model. This model can be used to easily transfer changes in route planning to the geometry of infrastructure buildings such as bridges. Furthermore the holistic model is used for the sequence planning in the infrastructure construction. Here the planning of earthwork processes is a major challenge. ForBAU worked out a solution with which the planning of earthwork can be improved by applying the Discrete Event Simulation. To improve the supply of materials in the execution stage a new logistics concept has been developed. The aim was to deliver materials to the place where they will be installed. As a result, transport, search and storage times can be reduced. In order to depict the progress made on the building site in the digital site model at any given time, RFID technology is employed to automatically collect, track and record the building components and operating materials.*

KEYWORDS: *digital construction site, ForBAU, parametric 3D modeling*

1. Status quo

In the present day and age, the construction industry is beset by major challenges. Ever more complex building projects need to be accomplished within increasingly tight deadlines. At the same time, due to the keen competition in this sector, prices are being forced down significantly. The German construction industry will only be able to meet these requirements if it succeeds in increasing its efficiency during the planning and execution stages. It would appear, however, that the current processing standards achieved by building contractors lag far behind those attained by other industrial sectors, particularly from the point of view of adhering to time schedules and cost stability.

There are numerous reasons for this: the difficult circumstances that prevail in the building industry in general, including the construction of unique "one-off" structures, dependence on weather conditions, the pronounced fragmentation of the sector and the high level of segmentation along the process chain. At the same time, only very limited use seems to be made of state-of-the-art information and communication technology compared with other sectors of the industry. Although mature software products are employed for specific partial assignments, there is still plenty of room for improvement in terms of both efficiency and quality, particularly with regard to enhancing data flow and putting existing digital data to further usage.

The resolute use of digital technologies throughout can achieve greater workflow transparency by reducing interfaces and optimizing the cooperation between the different parties involved in the projects. This potential is employed in many sectors, such as the automotive industry, shipbuilding or general plant construction. Until now, however, these concepts have only been put to restricted use in the building sector.

Recognizing that action was called for, the "Virtual construction site – digital tools for construction planning and

execution" (ForBAU) was set up in January 2008 with the aim of depicting a complex building project holistically by means of a single digital building site model. This simulated building site is employed as a central planning tool during all phases of the relevant project. An interdisciplinary team consisting of members of seven departments of Technische Universität München, the University of Erlangen-Nuremberg, Regensburg University of Applied Sciences and the German Aerospace Centre (DLR) joined forces to realize this vision along with more than 30 industrial partners including building contractors, firms of planners and engineers, construction equipment manufacturers and IT partners for digital tools. The interdisciplinary alliance was sponsored by the Bavarian Research Foundation from January 2008 to December 2010.

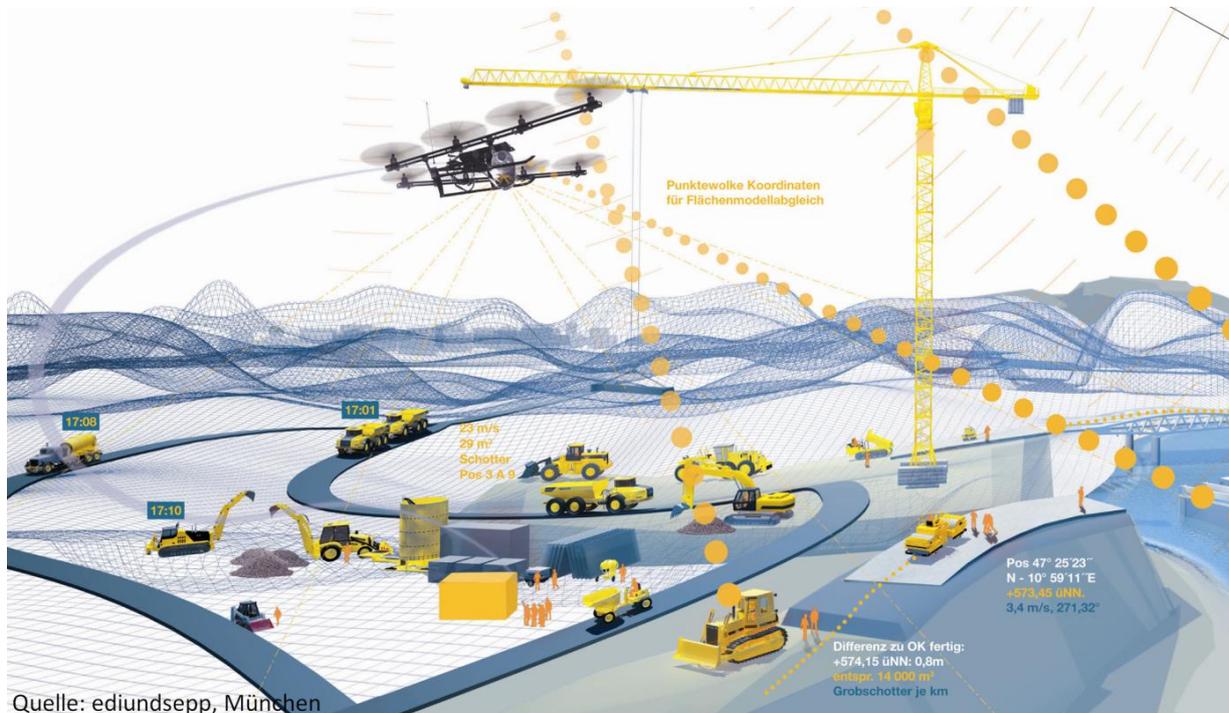


Fig. 1: The vision of a digital building site

2. New technologies for construction planning

The digital construction site is a virtual simulation of the real site. It contains valuable 3D planning data, making it possible to plan the construction sequences more carefully to begin with, then to test them on the model and subsequently to monitor the actual building process. The digital building site comprises various partial aspects which are described below in greater detail.

2.1 3D modeling

The ForBAU research alliance started out by observing the planning processes. The three-dimensional modeling helps to detect faults, such as building components colliding, before the plan has even left the building contractor's desk, thus keeping costly corrections on the building site to a minimum. Apart from three-dimensional models (see Figure 2), state-of-the-art CAD programs also support fully parametric ones. This means that adjustments – modifying the spacing of supports, for instance – can be implemented very quickly by changing one of the parameters. The aim of ForBAU is not just to simulate the building construction, however, but also to create a geological model of the subsoil and the terrain, to depict the construction site installations and finally to blend the various models together to form a single site information model – the digital construction site.

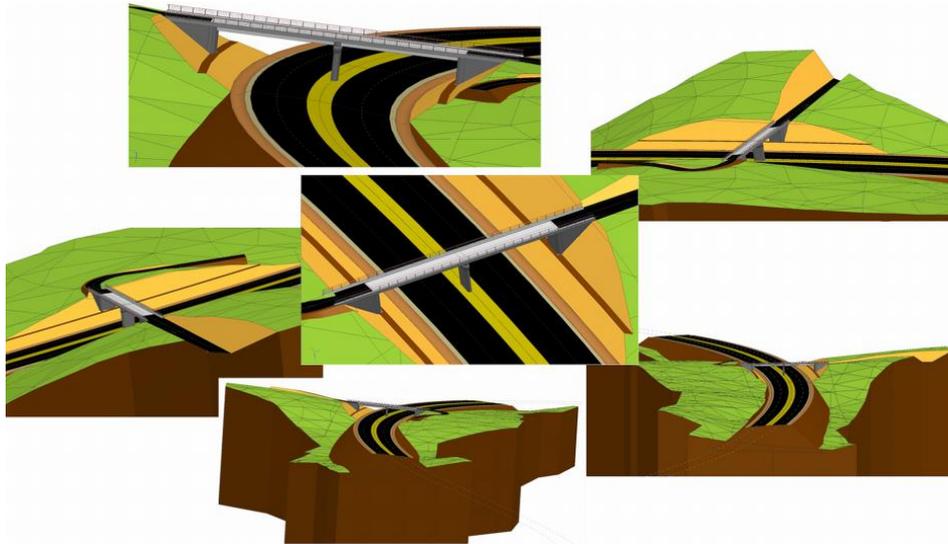


Fig. 1: Parametric 3D model of a construction site (Günthner and Borrmann, 2011)

2.2 Integrating submodels in the digital building site

The submodels depicted in Figure 3 need to be merged together to enable plans to be drawn up on the basis of a holistic model. The challenge is that the individual models are created using different, highly specialized applications, as is often the case in the construction industry. For this reason, part of the ForBAU project was devoted to developing special software known as an *integrator*.

One of the *integrator's* key purposes is to couple the drafted route, which is achieved with the help of established 2D drafting tools, with bridge models that are generated using parametric 3D modeling. By coupling these aspects it is possible to transfer any changes in the layout of the track, which frequently occur even at a later planning stage, to the bridge models, enabling the geometry of the bridges to be automatically aligned to the new route.

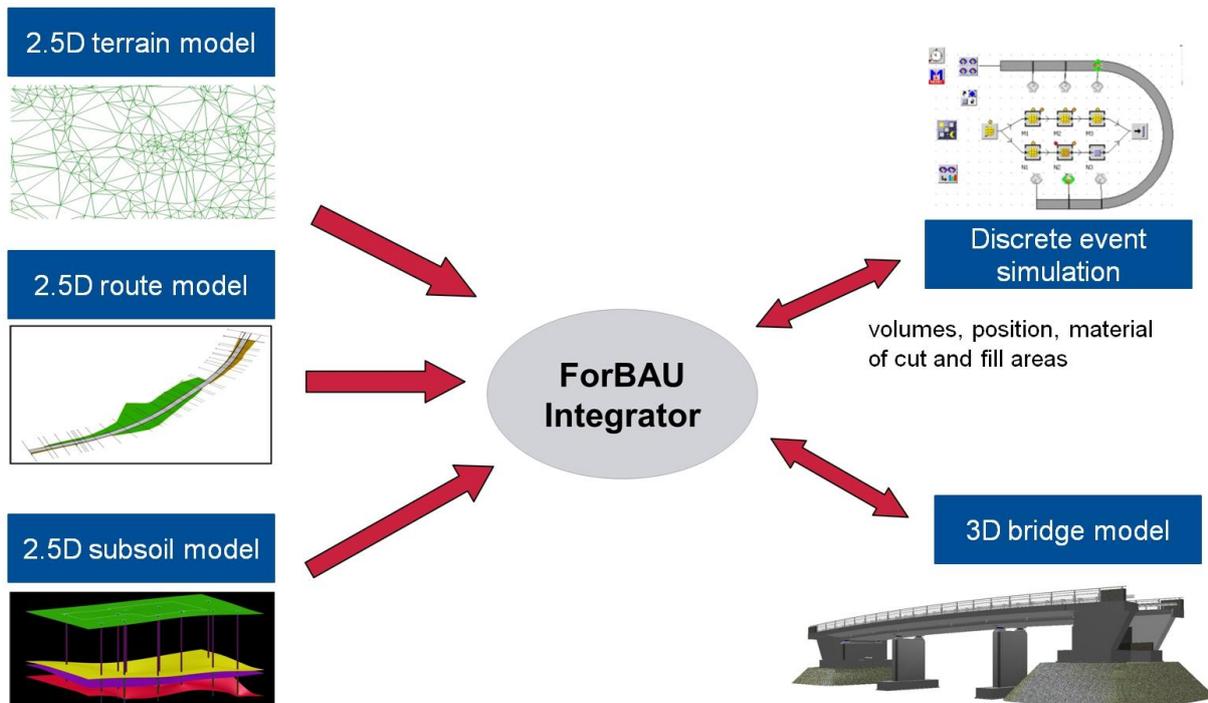


Fig. 2: The ForBAU integrator linking various submodels of the digital construction site together (Günthner and Borrmann, 2011)

This coupling process is implemented by importing the main track parameters (line of axis, gradients, cross-sections) with the help of the standardized LandXML format. The ForBAU integrator uses this information to create a 3D model of the proposed route. Another feature that is derived from the LandXML format is the digital terrain model (DGM), which maps the relief of the ground surface. The integrator is also able to import terrain models.

All this information on the proposed route and the surrounding area can then be transferred to the CAD system *Siemens NX* which was specifically selected for the ForBAU project by way of a tool for the parametric modeling of bridge structures. We begin by creating three 3D reference lines designed to describe the designated route for the track. They serve as geometric reference points on which the geometry of the components of the bridge model is based via parametric dependencies (Figure 4).

In the event that the course is changed in the route planning tool at some later date, the *integrator* is able to identify the relevant modifications and update the reference line.

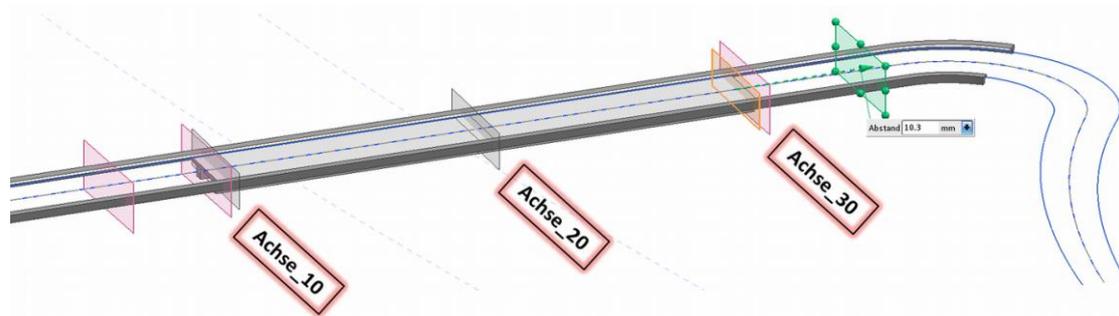


Fig. 3: Reference lines of the proposed route and the corresponding bridge geometry (Günthner and Borrmann, 2011)

Another key purpose of the ForBAU integrator is to calculate the volume of earth to be extracted or filled in. In order to generate this information, the integrator has to incorporate the 3D models of the subsoil and the terrain into the 3D model of the proposed route.

2.3 Building process workflow simulation

Operations scheduling in civil engineering is no easy task. Conventional methods of assessing the time-line for earthworks are currently confined to a number of individual pieces of equipment, whilst the mutual impact of several different operations can only be assessed through experience or by estimating possible influential factors. ForBAU has devised a solution for improving civil engineering operation schedules based on simulation technology. In this way, it is possible to optimize the use of resources by conducting numerous experiments during the simulation phase and analyzing the results. This involves using different plant combinations and alternative site facilities as variation parameters. Several track options can be taken into consideration and compared from the point of view of different material resources.

Another problematic aspect at big construction sites is finding the most economical cut and fill solution for a certain volume of earth. Until now, this was usually tackled by trying to reduce the average haulage distance between the extraction point and the dumping area. Transport costs not only depend on the distance, however, but also on the nature of the terrain, the vehicles employed and other general site conditions.

Against this background, ForBAU set about devising a way of saving on costs for various transport combinations using a workflow simulation. This can be followed up by a mathematical optimization process to ascertain how much earth needs to be dug out at which point and deposited at which dam in order to keep the total transportation costs per cubic meter to a minimum, thus reducing the number of trucks and the overall financial outlay. In addition, it is also possible to examine the feasibility of constructing a site road and to determine which haulage equipment is best suited for the scenario with or without a site road.

Importing the 3D model of the construction site into the simulation environment also provides a 4D visualization option which shows up any spatial and process-related collisions. The advantage of using simulation is that the detailed plans can be backed up by all the experiments to support discussions with everyone involved.

It also allows the simulation model to be continually updated during the construction stage as well as supporting a target/performance analysis of progress made with the building operations. In the event that delays nevertheless occur during the execution phase, due to unfavorable weather conditions etc., the ForBAU approach allows a flexible response by adapting the resources to the new situation in the simulation.

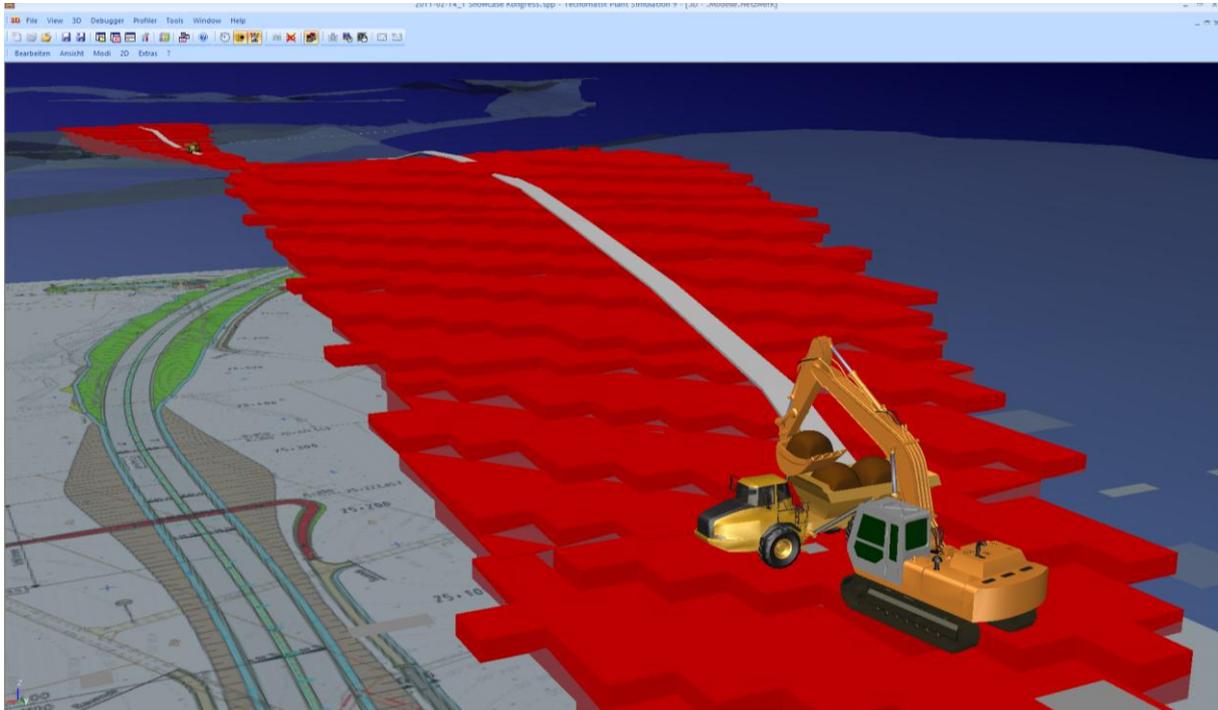


Fig. 4: Simulation of earthwork processes

3. Monitoring and control of the construction work

The benefits of good planning only become evident in the execution phase, as this accounts for the bulk of the construction costs. For the time being, however, the use of high-quality planning information suffers considerably from the lack of efficient means of comparing it with actual circumstances on the building site without delay.

Changes of plan are inadequately documented or not recorded at all. Information on current progress or delays in operations reaches the person responsible too late so it is impossible to respond quickly. In order to exploit the potential of the digital building site, it is therefore necessary to couple the virtual planning with the actual execution process. Information about the construction process needs to be relayed to the digital site information model in real time if changes in circumstances are to be documented promptly.

Process data means all the information that serves to record the progress made in the building project or describes the material and information flows. Nowadays it is typically collected on the building site in the form of written or digital documents (delivery notes, daily reports). These process data are often stored in a decentralized place, such as the foreman's or the construction supervisor's laptop, and there is usually some delay in forwarding it to the central IT system or the information is incomplete. It is only possible to control the construction operations efficiently and proactively, however, with the help of up-to-date information. So one of the goals has to be to simplify and speed up the recording and forwarding of the process data to a central IT system using appropriate technology and standardized interfaces.

3.1 Real-time data mining based on radio-frequency identification (RFID)

Process data are required for monitoring and controlling a building site - preferably in real time. Identification technology is employed to enable these data to be collected quickly and reliably during operations. One very promising type of identification technology is RFID technology. RFID stands for radio-frequency identification

and refers to a technology designed to read and enter information without any eye contact with the help of electromagnetic transmission.

A study on the topic of construction logistics (Günthner and Zimmermann, 2008) was conducted among contractors and planning firms at TU München in 2008. Among other issues, this study investigated the potential serviceability of RFID for the building industry. These companies anticipated the greatest benefits from improving the relevance of inventories by recording supplies without delay, prompt goods inwards and goods exit inspections and minimal administrative work by reducing manual operations. The filling out of consignment notes and the attendant incorrect documentation is one pertinent example. Other promising aspects that have been identified are the prompt project evaluation and utilization of a detailed database for later projects and a reduction in the incidence of missing parts.

It is estimated that this would cut administrative work by almost 14% and replace about 8% of the overall construction time with automatic data acquisition. Financial savings of up to 11% could be achieved through the organization, coordination and expedient reconciliation of operations, about 7% through the punctual delivery of consignments and another roughly 5% on storage facilities at the building site and the contractor's yard respectively. The results of the study will serve as a basis for various interesting scenarios for the industry and are to be developed and tested from the point of view of the labeling solutions given below.

3.2 Transparent material and process monitoring on building sites

Until now, most of the processes and the material flows on the building site could only be documented with the help of manual records such as daily logs and delivery notes etc. The new identification solutions based on RFID suggest numerous applications that might introduce more transparency into the operating procedures on the building site.

3.2.1 Labeling of drill pipes in special earthwork projects

In collaboration with Bauer AG, a labeling concept for special civil engineering pipes was devised. The aim was to document the lifespan of the individual drill pipe components. The number of drill pipe components supplied to the building site usually includes a few spares to be on the safe side. It may happen that certain drilling components are never used whereas others are needed for each drilling process, for instance, so different parts are subject to varying degrees of wear and tear. Documenting the operating hours provides new possibilities for drawing up maintenance schedules, which can be compiled from the long-term information on the database irrespective of the usage, work-load and soil conditions. As every side of a pipe component represents a functional surface that is subject to a great deal of wear and tear, they cannot simply be labeled using a RFID transponder, so it is impossible to document the operating hours in this way. The RFID drill-pipe screw was developed to solve this problem.



Fig. 5: RFID drill-pipe screw

The diameter of a drill pipe can measure anything up to four meters and they are joined and held together with the help of couplings. For safety purposes, the coupling sleeves are usually oversized, so it makes sense to replace drill-pipe screws with tight-fitting, plastic screws containing an integrated RFID transponder. This is read and recorded by the aerial on the mast during operation after it has been installed.

3.2.2 Labeling of shuttering components

Labeling formwork components not only helps to keep a careful track of these components in the contractor's yard and on the building site but also facilitates recording the hire period of each individual item and settling accounts. Other benefits include avoiding confusion, tracing damage back to the perpetrator and determining operating times for the relevant components, which in turn makes it possible to adjust servicing intervals and limit wear and tear. Shuttering systems either consist of a metal frame with timber shuttering sheets or are completely made of wood. It is important to distinguish between the two systems as metal has a significant impact on a RFID system.

An appropriate integrative solution for labeling modular shuttering panels within a metal frame is a plastic stopper with a built-in transponder. It can be inserted flush into a hole drilled in the formwork frame. It is essential to collaborate with a manufacturer before implementing this solution, as he would be responsible for drilling the hole and the inserting bushing during the production process.

Nowadays, wooden shuttering boards for formwork on the construction site are labeled with type labels in the form of small wooden plates designed for on-site integration according to the formwork plan. Label transponders can safely be fixed behind these plates. An alternative solution is to screw hard tags (transponders cast in plastic) directly on to the wooden support. Both solutions were tested in the trial runs.



Fig. 6: Labeled modular shuttering systems (hard tag on the left, Smart Label on the right)

Both hand-labeled hard tags and labels beneath the type plates were fixed to the wooden support in order to judge the reliability of the labeling. The labeled components were subsequently taken to the building site and used in the construction work. On being returned to the contractor's yard, they were checked to see whether the transponders were still in place and in working order. Without exception, all the results were positive. Both the hard tags screwed to the wooden supports and the labels fixed underneath the type plates were still intact and produced reliable readings.

3.2.3 Labeling of concrete components

The demand for prefabricated concrete units for use in construction projects is constantly on the rise. They are often custom-made to high precision standards for specific predetermined locations. These units undergo several processing steps from production to warehousing and transportation to the building site before they arrive at their final destination. Many of these process steps can be simplified by attributing certain information, such as a specific number, batch number or lifting and storage regulations to a component. Moreover, the use of these embedded transponders in the ongoing lifecycle of a structure – for maintenance or demolition work, for example – has considerable potential.

3.2.4 Mobile data transmission

It was to feed the constant flow of information from the building site into a centralized computer system that the concept of mobile building data transmission (mBDE) was developed. The purpose of this solution is to forward information on the current construction stage to the digital site information model in real time and to draw up a centralized progress record. Digital planning data can thus be coupled with the actual building site data and serve

as a basis for a performance analysis. This solution can support the following scenario: The foreman scans a component on the building site using a hand-held RFID device to check construction progress. If the device recognizes the in-built transponder, the component No. stored on the transponder appears on the display. The foreman decides whether to enter any more information about the component. If so, he can allocate the status (*delivered* or *completed*) and add a comment. The next step might be to record any defects in the form of a descriptive comment backed up with a photo and/or a voice memo.

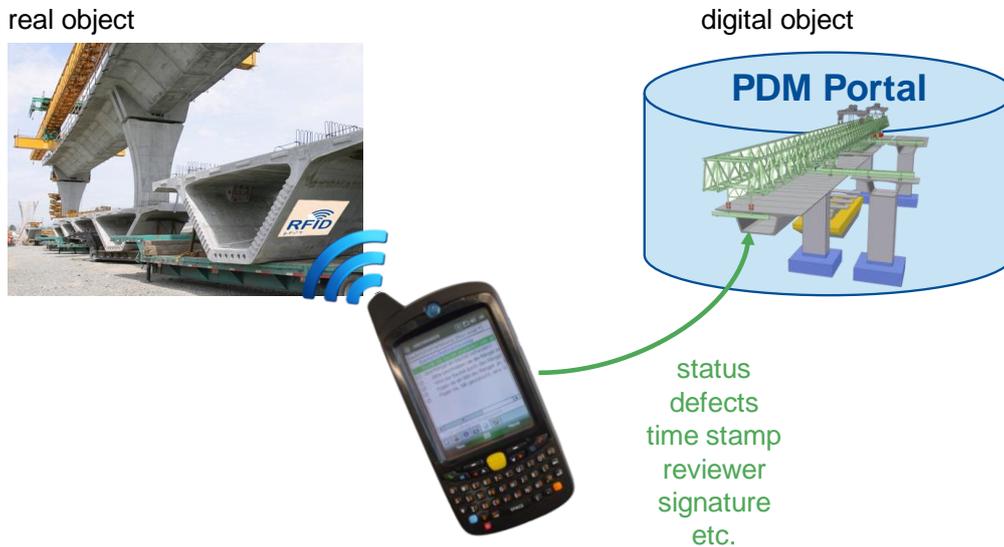


Fig. 7: Concept of mobile building data transmission

The application bundles the recorded component data (status, comment, picture, sound) in an XML file, sends it to the centralized system via a web server and attaches it to the digital component. A product data management system, PDM system for short, is used to record the information. The PDM environment also includes a built-in workflow, which updates the status of the component that was scanned (from *under construction* to *completed*, for instance) and colors in the component concerned in CAD according to that status. So the current status is documented on the digital building site at all times.

3.3 Just-in-time/just-in-position deliveries using last meter construction logistics

To improve material supplies during the execution phase, various logistics concepts were adapted and developed further. The aim is to deliver materials to the exact location where they are to be implemented so as to reduce haulage, search and storage times on the construction site. It was for this purpose that the *last meter construction logistics demonstrator* was devised. It combines RFID technology with satellite navigation to clearly identify and locate materials.



Fig. 8: Graphical user interface of the last meter construction logistics demonstrator (ForBAU, 2009)

Details of the materials to be ordered are sent to a mobile terminal or hand-held device so the foreman or site manager can select them via the graphical user interface (GUI), as required. The precise delivery point is determined with the help of GPS coordinates. This information package is transmitted to the supplier who commissions the goods on order according to delivery location and gives them a clear ID, using RFID transponders. For delivery purposes the driver is also given a mobile terminal, which works something like a navigation system. The mobile terminal guides the driver safely to the predetermined delivery location, where he then proceeds to unload the materials and scan the RFID transponder. Provided they are delivered to the right place, the foreman automatically receives a notification that the ordered goods have been unloaded on the correct spot. On receipt of this notification, the foreman checks the goods and confirms that the contents are correct, whereupon the order details are automatically forwarded to the accounts department for the bill to be settled.

4. Validation of results

In all phases of ForBAU the requirements, concepts and results were validated using real construction sites. Here, the concepts underlying assumptions were reviewed and the feasibility of the developments on the requirements of everyday building practice were tested and optimized. One example is the construction site "Mae West - Effnerplatz" in which a sculpture with about 52 m height had to be built between several buildings in Munich. Ahead of setting up the sculpture, a study of the lifting process of the sculpture with possible collisions was made by ForBAU. For this purpose, data from terrestrial laser scanning, airborne measurements were merged with 3D models from the crane and the sculpture (see Figure 10) and a 4D simulation and animation of the assembly process were implemented.

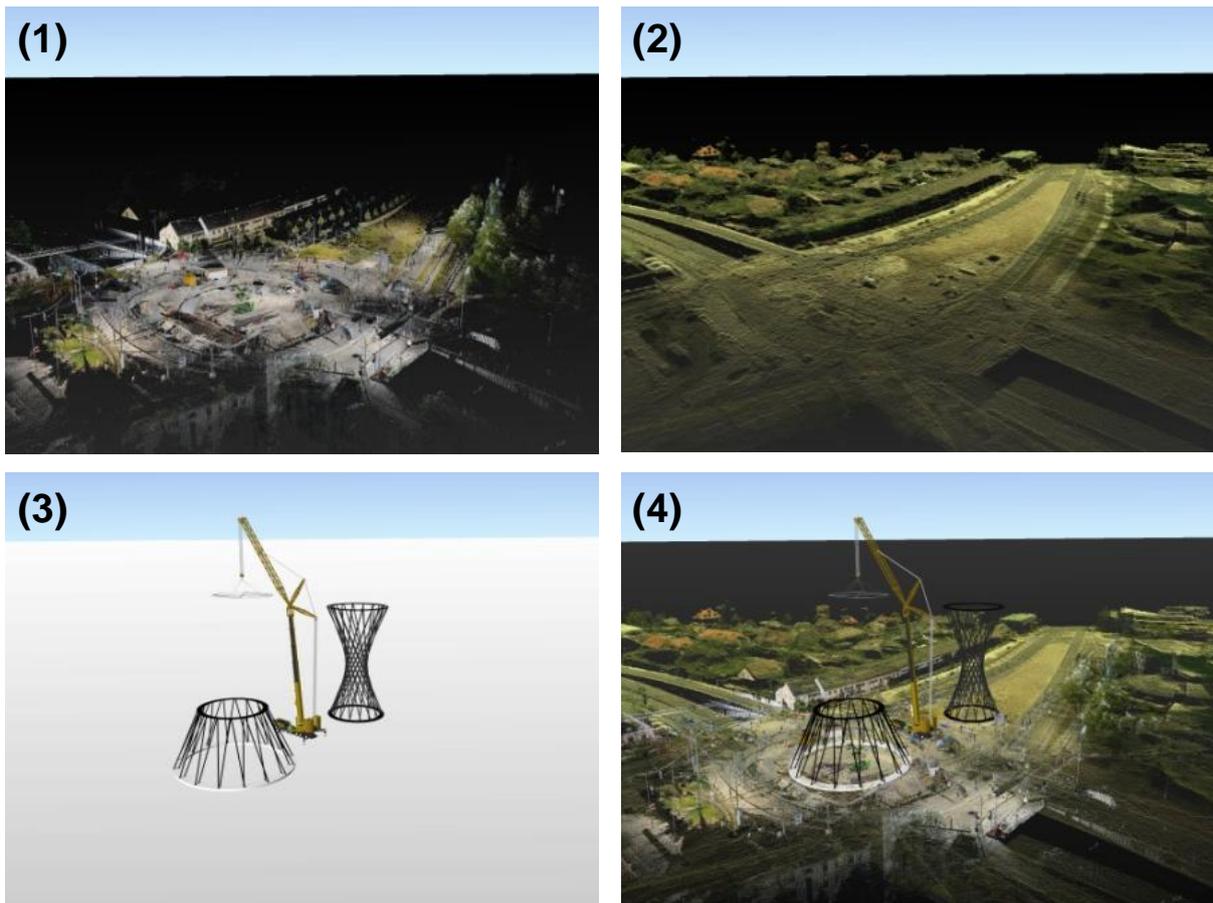


Fig. 10: (1) point cloud of terrestrial laser scanning, (2) point cloud of airborne measurements, (3) parametric 3D model of the crane and the sculpture, (4) point clouds merged with 3D models (ForBAU, 2011)

5. Conclusion

The aim of ForBAU, to create a "digital construction site", was given a strong impulse over the past three years by the advancement and coupling of various technologies. The solution was to apply three-dimensional parametric modeling and discrete event simulation methods to infrastructure engineering. With the help of smart interface programs such as the *integrator*, it is possible to merge various submodels to create a holistic digital building site model. It also involves devising ways of transferring these highly detailed planning data to the construction site, like the *last meter construction logistics demonstrator*, for instance. Here again, it is possible to integrate actual data into the digital site model by the mobile building data transmission concept. The developed concepts were based on construction sites, such as Mae West, reviewed and validated.

Acknowledgements

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