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Drafting through hoops

3-D modeling speeds design of roundabouts to enhance safety in Iowa

In early 2010, DuPont Pioneer International announced major expansions to its world headquarters campus in Johnston, Iowa, a move that will create 638 new jobs.

The expansion required widening and reconstruction of 1.5 miles of Johnston's NW 62nd Avenue, and state grants and other funds were raised to cover the $7 million project. Foth Infrastructure & Environment LLC secured the design contract and created an innovative project that saved money, beat very tight deadlines and efficiently used extremely sophisticated model-based design software—in fact, the project was a finalist in Bentley Systems' 2012 Be Inspired infrastructure awards program, in the Innovation in Roads category.

Foth saw an opportunity to cost-effectively minimize corridor delays, increase pedestrian safety and reduce the roadway's carbon footprint by proposing a nontraditional intersection solution based chiefly on a series of four multilane roundabouts, rather than a traditional approach consisting of signalized intersections. But this would be the first such use of roundabouts in Iowa, and Johnston officials were dubious.

"Basically, we met with the client and stakeholders, and they said no. Then, upon the conclusion of our presentation, they said maybe," said Foth Senior Technology Manager Blaine Buenger.

"And then they surprised us by taking a road trip to Carmel, Ind., where roundabouts are commonplace. And when they came back, they said yes."

This was good news, of course: Foth designers were certain that roundabouts were the right solution. But the approval process, combined with grant requirements and project timelines, now dictated a brutal schedule; from conceptual to final design of Iowa's first multilane, multiroundabout intersections in just under six weeks.

"It seemed unachievable," said Buenger.

Cut the draft

The project represented major innovation in infrastructure design at Foth, particularly in four areas:

Foth proposed the first use of roundabouts in Iowa, rather than traditional signalized intersections, and Johnston officials were dubious.

- Creating a 3-D model by combining output from several specialized tools;
- Automation of geometric and staking details and plan-set production;
- Provision of accurate 3-D models and associated detail during the bidding phase; and
- Minimized use of paper construction documents by use of Bentley's OnSite electronic field book system.

"Perhaps the greatest financial savings of the project occurred during the bidding phase," said Buenger. Full project data, including 3-D modeling, was provided to contractors in multiple file formats. The availability of this information increased the competitiveness of bids by reducing contractor risk and effort. In fact, the lowest six bids (of eight) were within 3.7% of each other, and the lowest two bids were separated by just $14,000. Most importantly, the accepted bid was 20% lower than the engineer's estimate, saving the city and state $1.7 million.

Drafting and design time also was greatly reduced. For example, a work flow was created that detailed more than 1,000 geometric and staking callouts on plan sheets. A Visual Basic application was used to automatically assign proposed elevations to each detailed point and, once points were created, additional tools labeled the points by defined sets and automatically generated point tables for use in staking routines. Foth estimated that this work flow alone reduced effort by 60%, saved 90 hours of manual drafting and cut 10 days from the project schedule, while also reducing errors and greatly simplifying design changes.

The use of specialized design modules—and aggregation into one model—was even more effective. "We saved about 120 hours of design and drafting time, compared to our previous methods," said Buenger. "And that cut about 14 days from our project schedule."

The bottom line is simple: Final design was completed in the allotted six weeks, without cost overruns. A task that seemed unachievable was accomplished with minimal errors and high measurable quality.

Complexity management emerged as one of the most valuable benefits of 3-D. The NW 62nd Avenue included roadway cross sections that combined two-lane boulevards, a raised landscape median, two-lane rural streets and the state's first series of roundabout interchanges.

Leaning forward

Foth has a large mechanical design division, which has championed the "lean practices" concept found in the mechanical and manufacturing sectors. The firm is determined to apply the basic principles of lean practices to civil projects, and the Iowa roundabouts were something of a pilot project for this approach. In practice, this meant closely examining work flows and information distribution and finding ways to eliminate redundancy and get more value from 3-D modeling.

"Lean practices are intended for factory lines and other manufacturing processes," said Buenger, "but the basic idea is to take the waste out, and we felt we had no choice but to do that here."

An example of a lean practice is the meeting protocol enforced throughout the project.

"We held two stand-up meetings every week, focused on a visual task board," Buenger explained. "The board helped everyone on the team to know what others were working on and when tasks needed to be accomplished in order to keep things moving. We used Microsoft Visio and OneNote to create and publish the board, and we also used OneNote as the central repository for design standards, project notes and links to project documentation. It really worked for us; the meetings were brief, focused, and we were able to capture the information they generated."

3-D design also is, in a sense, a crossover from mechanical design. It has been a staple of complex manufacturing for decades and is largely responsible for that industry's staggering productivity gains. 3-D design is becoming standard in architecture as well. But application to site work and to infrastructure tasks like storm-water management and roadway design is still new and Foth was at the cutting edge.

After initial survey work, supplemented with the use of lidar data provided by the state of Iowa, surfaces were created in discrete solutions specialized for drainage and roadway tasks and assembled into one model. The addition of lidar to Foth's work flow saved several hours of traditional topographical survey field work while also increasing accuracies of existing ground models. Having one 3-D model available as a reference early in the project facilitates multiple time-saving practices in middle and late design phases, for example:

It is easier to work with distributed teams

Foth was able to use designers and consultants from their entire global network and call on outside consultants as needed. The single reference model enabled virtual onsite measurement using tools for interference and clash detection very similar to routines used in 3-D manufacturing and plant design.

Accurate visual presentations are a byproduct of the design work

Rather than putting designers or specialists to work separately on renderings or models for use in presentations and approval applications,

the Foth team could simply use views of the actual model.

Construction staging becomes clear

"Half of Johnston's schools and a fire station are located on the east end of the project, and NW 62nd Avenue is one of just two routes across Beaver Creek," Buenger explained. "So two-way traffic had to be maintained at all times. We were able to use alternate surfaces within [the software] corridor modeler to piece together construction phases—the 3-D model and interim surfaces were absolutely essential for this task."

Complexity is tamed

Consider just the pedestrian aspects of this project. Since the project corridor passes right through the headquarter's complex, pedestrian safety was a primary design consideration. "Each leg of each roundabout contains pedestrian ramps that had to meet ADA and PROWAG requirements," said Buenger, "and we also designed a 12-ft by 8-ft pedestrian underpass. The amount of geometric and staking details was just staggering." The team took advantage of the 3-D model by using a Visual Basic routine to extract and apply proposed elevations to particular coordinates. The routine reduced errors and sped up production of plan sheets.

Complexity management emerged as one of the most valuable benefits of 3-D infrastructure design. The NW 62nd Avenue included roadway cross sections that combined two-lane boulevards, a raised landscape median and two-lane rural streets; the state's first series of roundabout interchanges; pavement widening and full reconstruction; a two-lane bridge with a pedestrian trail; major new storm-water-management facilities; stream realignment and more.

"Design tool interoperability was extremely important," said Buenger. "For example, we were able to export the design data from Geopak's drainage modules directly into StormCAD for advanced network modeling. This simplified hydraulic calculations, sped up design and greatly eased the approval process. Without the ability to migrate data between individual solutions and pull everything together in one model, we would have never met our deadlines."

3-D design has been a staple of complex manufacturing for decades, but application to site work and to infrastructure tasks like roadway design is still new.

Machines take control

"Creek realignment was a major part of this project, and in fact we modeled the entire existing creek area and proposed alignment," said Buenger. "We were then able to hand off these models to the contractor for use as machine-control surfaces." In fact, GPS and the new Foth-provided creek alignment facilitated machine-guided channel excavation, a very new practice in Iowa. This virtually replaced traditional survey layout. Though four stakes were set, Buenger said they were not needed by the excavator operator and were basically placed to increase the comfort level of inspectors and the site foreman.

"It really wasn't our mandate to increase use of machine control—that's up to the contractor, of course." Buenger explained. "But obviously, a lot of time was saved doing it this way. This kind of staking is difficult to do anyway, and it usually comes down to a skillful operator's judgment." But in this case, he said, Foth was able to use aerial imagery of the new creek alignment to verify very exact excavation work. Machine-controlled excavation appeared to be faster and more accurate than traditional methods. The excavation contractor also was able to skip rough grading, another significant source of savings.

T-bone takeout

The innovative nature of the actual project should not be overlooked. Traffic studies suggest that, compared with traditional intersection design, the roundabout series will result in a 90% reduction of fatalities, a 76% reduction in injuries and a 35% reduction in all crashes. This improved safety is due mainly to slower vehicle speeds in roundabouts, fewer vehicle conflict points and, especially, fewer severe vehicle conflict points. In roundabouts, there are almost no opportunities for T-bone or head-on crashes. Rather, the crashes that do take place are relatively safer sideswipes and rear-end collisions.

Additionally, pedestrian fatalities are reduced by a factor of 11, and bicycle crashes are reduced, simply by reducing average intersection speeds.

Even with the average intersection speed reduced, average corridor speed is increased by the elimination of signalized interchanges and routine stops. The elimination of signals, idling and stopping also works to reduce gasoline consumption and vehicle emissions and eliminates the cost of installing, powering and maintaining signal lights. Roundabouts even require less pavement. There are a lot of wins for DuPont and Johnston, and the trip to Carmel, Ind., was well worth it.

A roadway redesign project—even a major project like this one—is not, in fact, special; they are ordinary and take place constantly all over the world. But each such project—and every infrastructure project—does represent an opportunity to do something special. By applying the best technology to the best roadway design, Foth and the city have made a positive contribution to life in Johnston, Iowa, and the benefits of their work will reach across generations. **TM&E**

Stocking is a licensed land surveyor who now writes full-time on infrastructure topics.