The Digital Factory
From Concept to Reality

A Bentley Solution Paper for Automobile Manufacturers

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INTRODUCTION

Bentley Systems is uniquely qualified to offer automobile manufacturers a flexible, scalable solution for planning, engineering, constructing, operating, and maintaining their manufacturing facilities. The Bentley solution for factories reduces costs in pre-production and compresses time to market. Equally important, by preserving the valuable data generated from planning and making that data accessible to all stakeholders, the solution optimizes information management for the lifetime of the facility.

The Digital Factory - From Concept to Reality

Advanced automation, precision robotics, just-in-time delivery – these technologies represent enormous achievements in automotive production. But in today's global business climate, with traditional markets stagnating and competition from emerging economies increasing, automotive manufacturers must look beyond production to maintain their position in world markets. Automotive factories represent a huge percentage of manufacturers' total assets and annual investments. Maintaining these facilities to meet the challenges of changing markets, stringent environmental standards, and a leaner work force has become more crucial to the company's success and a lot more costly. Not only must today's factories be flexible enough to accommodate multiple product series and short product lifecycles, but periodically a significant design change may require a complete reconfiguration, or the construction of an entirely new facility.

As important as these facilities are to automotive manufacturing companies, until newly designed vehicles roll off the production line, new structures and plant reconfigurations are a liability, not an asset. As a result, manufacturers are seeking to shorten every phase of production planning, including planning related to the facilities that house production operations. Additional savings could be realized in operating and maintenance costs, but these opportunities have been difficult to predict due to variables such as the facility's design parameters, the building materials used, and the costs associated with constructing and maintaining the supporting infrastructure. Because each of these variables offers significant potential for savings, manufacturers would benefit from the ability to access and analyze all relevant data to better understand where costs could be reduced.

As the workflow moves forward, dependencies between individual steps typically require team members to access information about previous or parallel tasks. In practice, sharing this information has been difficult.

Figure 1: The Bentley factories solution consolidates planning, design, construction, and operational data for the entire factory lifecycle.

Production facilities represent a large percentage of the automobile manufacturer's total assets and yearly investments, and they account for a necessary and significant portion of overall product costs. Therefore, significant cost savings and improved returns on investment can result from the integration of facility planning and production planning processes, and the consolidation of operational and maintenance information into a homogeneous, readily accessible environment.

This is where the Bentley solution for factories can help.

Bentley Systems is the world's leading company dedicated to providing comprehensive solutions for the infrastructure lifecycle. With so many resources to draw on, Bentley can offer a flexible, scalable solution to the automotive industry for planning (including site selection and layout), designing, engineering, constructing, operating, and maintaining manufacturing facilities. The Bentley factories solution reduces costs in pre-production and compresses time to market. In addition, by preserving the valuable data generated in planning and making it accessible to all stakeholders, the Bentley factories solution optimizes information management for the entire lifecycle of the facility.

The Challenges

Factory planners in today's business climate realize that success often hinges on the ability to frontload information. An integrated approach that makes data available as early as the conceptual stage offers a significant potential for savings. For example, by querying a database, planners might detect free manufacturing space and avoid new construction altogether by optimizing existing facilities.

If planners decide that a renovation or a new facility is needed, one of the first steps is to obtain permits from local authorities. This isn't always an easy task since new structures often must comply with exacting standards for external appearance and environmental impact. Making matters more difficult, 2D paper drawings may be too abstract to convince either regulating agencies or affected residents. More realistic and appealing representations – such as those created from fully rendered 3D models – are much more effective.

Beyond construction, automotive manufacturers would benefit from a completely transparent set of data generated at every phase of the factory lifecycle: planning, construction, operation, maintenance, and renewal.

As the workflow moves forward, dependencies between individual steps typically require team members to access information about previous or parallel tasks. In practice, sharing this information has been difficult. Though specialists are each working to achieve the same objective, their individual contributions may be unavailable to other team members or, at best, difficult to access in the latest versions. Such information isolation can result in increased rework, more time and cost for the whole project, and lower quality. For example, if all members of the design team do not have an accurate view of the total project, interferences between different systems and structures may bring about costly field changes during construction.

The 2D approach allows only limited information exchange and results in extensive changes and rework. Review processes, including those with contractors and fabricators, require multiple iterations of expensive printed documents. In contrast, the 3D digital process enables online reviews and improved communications for the entire team, thereby minimizing changes and rework. Design team members can work on their assigned areas concurrently because they have access to the same 3D model. Most importantly, they can perform design analyses on the master model and discover problem areas before they result in costly field changes. Further, with engineers, contractors, and fabricators all having access to the model, the review process is faster, leading to earlier production starts.

Beyond construction, automotive manufacturers would benefit from a completely transparent set of data generated at every phase of the factory lifecycle: planning, construction, operation, maintenance, and renewal. They would be able to query a common repository at any point to improve the quality and economy of their operations. Manufacturers with multiple locations could compare data among their separate facilities and use it for future planning and improvements.

The factory lifecycle is a combination of discrete processes that demand high integration and collaboration across various internal departments and external parties. Broadly speaking, the workflow stages for planning, designing, constructing, operating, and maintaining a factory are similar throughout the automotive industry; however, each

company has its own specific requirements and each project its own set of challenges. Therefore, solutions must be flexible enough to adapt to each case.

The Bentley Factories Solution

Manufacturers have coined the phrase "digital factory" to designate a network of digital models, methodologies, and applications used to integrate the planning and design of manufacturing facilities with the manufacturing process itself. Companies such as Daimler, General Motors, Volkswagen, and Toyota have made significant progress toward realizing this vision. Using Bentley's factories solution, they have designed and constructed facilities with fewer delays and cost overruns and achieved a faster start of production than was possible using previous methods. In fact, Bentley's factories solution has become the de facto standard for most members of the Verband der Automobilindustrie (Association of the Automotive Industry) in Europe.

The factory lifecycle starts with the site planning, design of the facilities and infrastructure, followed by the construction phase, the installation of machinery, and finally the start of production.

Figure 2: Digital Factory Planning includes process planning, logistic planning, factory planning and ERP planning.

The factory planning process is central because it typically brings together all the available as-built information, determines the basic constraints of the complete factory before detailed planning is undertaken, consolidates information in the final planning phases, and provides information for manufacturing operations. To create a detailed factory layout that can be used to construct and operate a manufacturing facility, all previously created information must be integrated and analyzed. This is the only way to arrive at an optimal factory layout that supports the manufacturing process, optimizes space, production, and logistic requirements, links with enterprise resource planning systems (ERP), and guarantees a high maintainability and profitability.

The digital factory concept today focuses on an integrated planning process that includes product design, process planning, and planning of the manufacturing operation. Integration shortens the time and delay between these steps and unites the different planning groups. It offers dedicated tools and makes accurate and up-to-date information available to all of the project team members right at the beginning of the planning phase and throughout operations until the facility is renewed.

Bentley's goal is full realization of the digital factory vision: to unite planners, designers, architects, engineers, contractors, subcontractors, and owner/operators throughout the entire facility lifecycle. This means ensuring that everyone always has accurate information to make the best decisions for their tasks, regardless of their location, time zone, or discipline.

Design teams using the Bentley factories solution have been spared countless hours deciphering abstract 2D drawings, not to mention weeks and months of iterative review cycles.

With all planning intelligence unified in an accessible form, factory planning becomes a central, enterprise-wide information source instead of an event-driven planning tool. Factory planning also provides the starting point of factory construction and operations.

How Does the Bentley System Help Factory Planners?

Factory planning normally starts with a decision to produce a new product, move into a new market, or expand production. A team of specialists defines the required size and capacity to determine the framework of the new project. Then the factory-planning team is asked to use these calculations to quickly produce a draft and a realistic estimate of the size of the project, location of the new or renewed facility, and the related costs. Based on this data, executives will make decisions about whether to build on a greenfield, reuse existing facilities, buy a facility, or replace an existing one. Then the detailed planning starts. Two parallel processes are initiated: product and process planning and factory planning. The related financial and logistic studies are begun as well.

The factory lifecycle starts with the site planning, design of the facilities and infrastructure, followed by the construction phase, the installation of machinery, and finally the start of production (SOP), when the factory goes into operation and is supported by maintenance. Planners have to consider all aspects of the facility, which is much more than a set of walls housing production. It is a multi-building campus with an infrastructure as complex as that of a small city. It includes buildings for business offices, equipment maintenance, and possibly a cafeteria for the workers. Planning needs to cover land to be surveyed and mapped, terrain to be engineered, roads and often a railroad spur to be constructed, and a utility infrastructure that must exist in harmony with all the other systems that support production and factory personnel.

Planning the Factory Site

Multiple disciplines are involved in planning the factory building site. The Bentley factories solution allows factory planners to study photographs and aerial views and to integrate maps of the building site and adjacent land into the planning workflow.

Bentley supplies tools for demographic studies to determine the impact of the facility on the environment. Terrain modeling helps the civil engineers on the team make decisions about grading the land, such as how much dirt to cut or fill and whether retention ponds will be needed for storm drainage control. Bentley also provides products for placing the utility infrastructure on the site and in alignment with the building footprint. Since automotive manufacturing requires the capacity to move large quantities of heavy materials and to transfer finished products to transportation hubs, Bentley provides applications for designing and maintaining roads and railroads on the site and connecting them with area transportation networks.

MicroStation is also the basis of applications for designing the factory site: imaging, mapping, terrain modeling, road and railroad design, and design of utility networks.

Planning the Factory Building

For designing the factory structure and internal systems – mechanical, HVAC, plumbing, electric, and communications – the Bentley factories solution offers a full range of architectural and engineering tools for design and analysis. These applications are scalable and appropriate for projects ranging from renovating a small facility to designing a multi-building complex.

Even when designing a simple structure such as a private residence, architects use automated design tools to detect interferences among water and sewer pipes, steel beams, gas lines, and electrical networks. Designers using the Bentley factories solution design structural and utility systems to support the largest and most automated production lines in the industrial world, where vehicles ranging from golf carts to eighteen-wheelers are assembled largely by robots. Working with a 3D master model, project teams can view the facility design on multiple levels and analyze its components in relation to the whole. Changes made in one area are reflected throughout the model and in the supporting documents.

Design teams using the Bentley factories solution have been spared countless hours deciphering abstract 2D drawings, not to mention weeks and months of iterative review cycles. They also have avoided the skyrocketing costs of errors discovered during construction by being able to detect interferences during the design stage. And they benefited from faster order placement and more just-in-time deliveries to construction sites as a result of their ability to exchange 3D shop drawings with steel mills, preformed concrete manufacturers, and other suppliers.

Planning for Ongoing Factory Maintenance

For ongoing operations and maintenance, the Bentley factories solution allows access to facility-related data from many sources, including the documents, models, and drawings created in the planning workflow. CAD drawings can be enriched with facilities management information, such as cost-center and occupant data, and then used for automatic area calculation based on a variety of industry standards. Data from other corporate resources in databases, spreadsheets, and other types of documents can also be integrated into the data model. Analysts looking to improve operational efficiency are able to query their

databases at any point. For example, with access to the calculations used to determine the type of windows to install, they can confirm that the added expense for more efficient windows was justified by lower heating and air conditioning costs. In addition, companies with multiple locations can compare operational costs among facilities and use the information for future planning and improvements. And accountants are better able to assign expenses to particular products, processes and facilities for tax purposes.

What Does Bentley Bring to the Digital Factory?

The Bentley factories solution provides the framework that enables design teams to visualize the whole automotive assembly line in the context of a real-scale digital factory.

The Bentley factories solution includes:

- A large portfolio of applications serving the many design and engineering disciplines in factory planning
- State-of-the-art data management for the entire factory lifecycle
- Visualization capabilities for the whole team, including internal reviewers, external contractors, and regulatory agencies

Design, Engineering and 3D Modeling

Bentley design and engineering products are based on MicroStation®, Bentley's flagship product for the design of all types of infrastructure and buildings. Because MicroStation is a superb computer-aided design product supporting industry standards and structured workflows, it is an ideal platform on which to base the many applications and toolsets required to create a facility as complex as an automotive factory.

MicroStation-based products include applications for architecture, structural and mechanical engineering, electrical engineering, communications, piping, HVAC, and many more areas for the planning, layout, and construction of the factory building itself. The intelligent 3D modeling capabilities of the MicroStation-based applications allow the project team to work from a single master model so that team members can see their individual contributions in relation to the whole and, thus, more easily identify design flaws.

MicroStation is also the basis of applications for designing the factory site: imaging, mapping, terrain modeling, road and railroad design, and design of utility networks. MicroStation applications are used at all stages of the manufacturing facility lifecycle, and can be integrated with other industry-standard applications in the business area, such as SAP.

Information Management

To achieve communications throughout the workflow, the Bentley factories solution includes ProjectWise, an engineering project team collaboration system. The system includes server software for caching data in multiple locations, thereby making available the latest versions of project drawings and documents to all project team members, including those in remote offices. Changes are automatically reflected in associated drawings and documents such as bills of materials.

ProjectWise allows all team members to view the model as a whole or to isolate specific components for viewing individually, for example, the separate systems of pipes carrying the fluids for the production process. Team members can perform individual or collective reviews, analyze their structures for interferences, and share design components throughout the process. ProjectWise can assemble 2D and 3D project content from hundreds of architectural, engineering, construction, and infrastructure design applications. It supports multiple industry-standard file formats, including DGN and DWG, PDF, JPEG, and TIFF, as well as IGES, STEP, and 3DS. In addition, shop drawings automatically generated in 2D or 3D can be digitally exchanged with contractors and off-site fabricators, speeding up the approval process and providing more accurate and comprehensible drawings at the construction site.

An inability to cooperate with professionals in other fields resulted in more time and costs for the whole project and contributed to lower quality.

Visualization

The Bentley factories solution provides the framework that enables design teams to visualize the whole automotive assembly line in the context of a real-scale digital factory. All the accurate geometry information of the assembly line equipment, the complex production processes, and adjustments to the product line can be simulated in exact 3D models of factory facilities, which are much better than 2D schema. Provided with rich information from the digital factory model, planners can ensure that all is correct when the factory is realized, and that no surprises materialize afterward. For example, Daimler's Power Wall system, where the design team projected their model at weekly design review meetings, helped Daimler reduce the interference points from 1,500 to 15 before its new Van Technology Center in Stuttgart was built. It helped them deliver the project on time and on budget.

The visualization component of the factories solution provides:

- 3D visualization of space efficiency
- 3D real-scale simulation of the assembly process
- Interference (both dynamic and static) detection beforehand
- A decrease in rework, leading to substantial cost savings
- Shortened duration of product line reconfiguration and modification
- Access to accumulated design information for later maintenance

Factories Solution Data Flow

A goal of the Bentley factories solution is to eliminate information isolation. In yesterday's design environment, the information for which individual team members were responsible was very specific, and their focus was on their own needs. An inability to cooperate with professionals in other fields resulted in more time and costs for the whole project and contributed to lower quality. For decision makers, the asymmetry between the information provision and the need to make early decisions brought

about painful dilemmas. Inescapably, important decisions having a crucial impact on later project stages had to be based on insufficient information. The Bentley factories solution addresses the need for accurate, timely, and accessible data at all planning stages, including:

• **Model creation:** Bentley's factories solution can integrate data from different sources and use it in the creation of the factory model. So, even at the start of the planning process, documents and drawings are readily available to decision makers. About 75 percent of today's engineering data is created as MicroStation DGN or AutoCAD DWG files. The unique capability of MicroStation to natively read and write both file formats provides easy access to this data and allows designers to use pre-existing drawings as a starting point. As the various disciplines make their contributions to the project, their designs are combined in a single model. MicroStation plus dedicated tools and applications – civil engineering, architecture, structural, piping systems, and HVAC – are used to support the planning team in the creation of the facilities design and in the layout and planning of the infrastructure. They are also used to create the drawings that may be needed for external and internal reviews.

Shorter meetings and approval cycles and the ability to work on separate design segments concurrently are just some of the advantages that the Bentley factories solution has delivered.

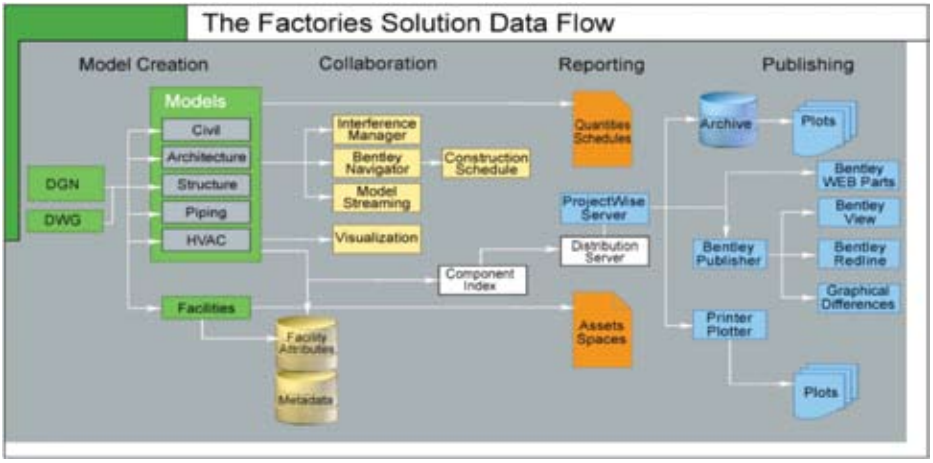

Figure 3: How Bentley supports the data workflow in the factory-planning process.

• **Collaboration:** ProjectWise, the backbone of the factories solution, offers a system platform on which all the participants can exchange ideas, supply requested information, negotiate design conflicts, and freely engage in other collaborative activities. Designers can share components of each other's drawings: structural beams, walls, columns, HVAC, and piping, for example. Also, the review process is accelerated. When a drawing is ready for review, the designer sends a notice to the reviewers. With both designers and reviewers having access to ProjectWise, a reviewer can open the drawing, make comments, and notify the designer, who then makes the changes. The updated drawing is immediately available to all team members. Contractors and construction supervisors can also be notified of last-minute changes – before valuable skilled labor and materials are committed.

• **Reporting:** The solution uses the information in the project model to generate many types of reports, including bills of materials and scheduling – all of which are automatically updated to reflect design changes.

• **Publishing:** The solution includes all the required software for printing and plotting drawings and models. Publishing provides the tools to make the printed drawings available for the project participants in planning and on the construction site and, at the same time, available for controlling or reviewing through management. The integration of these processes and consolidated information in a homogeneous, accessible environment constitutes a large return and cost-saving potential. The risk of planning mistakes is lower when more project participants have access to the actual information, and the iterations can be faster.

Only with a complete 3D digital building model was the team able to adapt the new building to the interior production facilities and match the subterranean infrastructure.

The Bentley factories solution creates a collaborative environment that includes not only the project design team but also construction crews, suppliers, and fabricators. Direct data exchange across the design/fabrication/construction supply chain enables direct 3D modeling data transfer, which can cut weeks from the time-consuming process of ordering supplies and off-site fabrication. Later, after the facility is completed, the design and construction data becomes a valuable asset for the remainder of the factory lifecycle.

Bentley Digital Factory Successes

With support from Bentley, world-renowned automotive companies are making significant progress toward realizing the digital factory vision. Daimler, General Motors, and Toyota, together with their architects, engineers, suppliers and fabricators, have met compressed schedules, controlled costs, resolved complex renovation challenges and achieved faster production starts. These implementations demonstrate the benefits that the Bentley factories solution can bring to the manufacturing facility design workflow today, and show that Bentley technology provides a solid foundation for a fully integrated future.

These are some of the benefits that Bentley users have realized:

• **Informed early decisions:** The signature characteristics of Bentley's solution – a holistic, comprehensible view of the model even in the project's early stages; the ability to generate documents and realistic representations; and compatible data accessible to all team members – help planners make sound design decisions, provide information to regulatory agencies, and issue reports based on integrated information that is updated with every design change.

• **Meeting compressed design schedules:** Automotive manufacturers must use every means available to squeeze wasted time out of their workflows. Shorter meetings and approval cycles and the ability to work on separate design segments concurrently are just some of the advantages that the Bentley factories solution has delivered.

• **Optimizing factory layout for production efficiency:** Automotive factories, among the most complex of all manufacturing facilities, pose unique design challenges.

The toolsets allowed the design staff to depict all elements in their true magnitude, removing the abstraction of traditional drafting practices.

Figure 4: Building No. 60 for Daimler Gaggenau. Kohlbecker Architekten & Ingenieure developed the working model with Bentley's MicroStation, Bentley speedikon Architectural, and InRoads. From this model the construction drawings were easily derived for printing.

Working from a master 3D model helps team members establish compatibility among the different systems that constitute the structure and avoid costly design errors.

• **Faster fabrication and construction:** Being able to exchange intelligent 3D models with suppliers and fabricators allows the design team to compress the approval process for ordering materials and off-site fabrication. Construction crews working from detailed 3D models waste less time and make fewer errors than they did when interpreting multilayered 2D drawings.

Daimler

In 2001 Daimler decided that "all new buildings would be modeled completely in 3D in order to create the conditions for the process planning vision." Its target was to reduce the time for bringing a new or renovated facility online. In planning the Daimler Van Technology Center, the design team worked from a MicroStation 3D master model representing the actual detailing of their project. At biweekly meetings, the participants reviewed each other's 3D models displayed on a projection wall and then received their "homework," an electronic printout with the coordinates of the clashes and other necessary modifications to be made before the next meeting. Thus, the planners avoided misunderstandings and the resulting lost time. The 3D views made the results clear and understandable, and meetings were shorter and more effective.

In 2004 Daimler engaged Kohlbecker Architekten & Ingenieure to design a new car manufacturing facility at Gaggenau for the manual production of gear boxes for valuable antique Mercedes-Benz cars. One of their challenges was integrating the appearance of the building with the existing surroundings. Kohlbecker found that photorealistic visualizations of the building were "enormously helpful in obtaining authorities' approval and to fulfill nearby residents' aesthetic requirements." These presentations were produced from early versions of their 3D models.

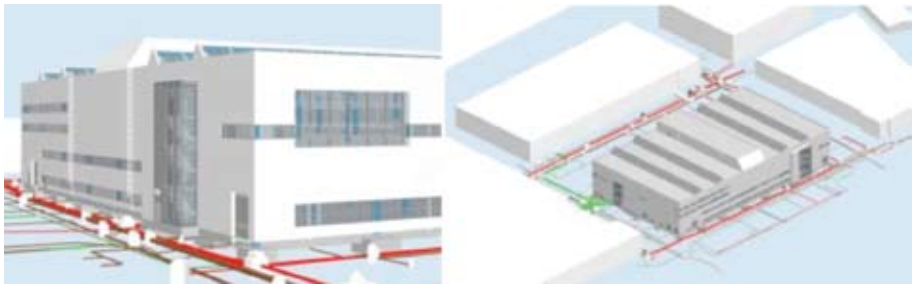

Figure 5: Daimler's car manufacturing plant in Gaggenau. The project met three major challenges: planning the two-story production building, matching existing, subterranean infrastructure equipment within the plant, and the aesthetical integration of the building into the surrounding townscape.

Use of the ProjectWise servers was a key factor in the success of the project. The team was able to share the latest information and to minimize the chances of re-work due to the use of obsolete versions of the design documents.

Another challenge was designing for production on two levels due to limited space. Only with a complete 3D digital building model was the team able to adapt the new building to the interior production facilities and match the subterranean infrastructure. The existing plant had grown for several decades and the area was packed with older buildings. Underground, there was a complex infrastructure network with which every new building had to be compatible. A particular difficulty involved the drainage pipes, which ran on several levels and were not constructed in a simple rectangular grid. Compatibility and clash-free construction could not have been established with conventional, 2D drawings, but were guaranteed by the 3D model in the Bentley factories solution.

Daimler made further strides by integrating its proprietary Factory Planning and Information System (FAPLIS), based on Bentley's MicroStation, with its process planning system, Delmia Process Engineer. Previously, to create a representative layout in FAPLIS, engineers had to place the planning objects such as robot cells or assembly stations – already placed in Delmia – a second time. On the planning side, necessary architectural elements such as walls, columns, HVAC, and so on, had to be acquired or created even though they already existed in FAPLIS. This duplication of work occurred several times with each change in planning.

The solution was a productively applicable bidirectional connection between the systems, both on the geometrical and the structural level. The technical realization came via the development of a simplified structured tree representation of the Product Process Resource hub within MicroStation as well as multilevel translation from geometry between MicroStation and CATIA.

Toyota Motor Corporation

Toyota's motor manufacturing assembly plant in San Antonio will be one of Toyota's latest North American manufacturing facilities. When completed, this facility will produce 150,000 full-sized Tundra pickup trucks per year. SSOE, Inc., the architect/engineering firm for this project, used Bentley's factories solution to complete the contract documents for the manufacturing shops and the central plant.

The routing of the utility distribution networks imposed a critical design constraint. The ducts needed to be placed in specific locations to avoid interferences with the

manufacturing process, both of which needed to exist in harmony with the structural steel systems. Compounding the task of designing these relationships was an extremely aggressive design schedule, which mandated that decisions about utility routing be made as early as possible. Bentley's Building Information Modeling tools were instrumental in making these decisions. The toolsets allowed the design staff to depict all elements in their true magnitude, removing the abstraction of traditional drafting practices. The design team could insure that large diameter pipes, air ducts, and electrical cable trays were routed in harmony with one another. Using the modeling tools as true design tools, designers and engineers were able to resolve conflicts at both the "micro" and the "macro" level. They completed the contract documents for manufacturing shops and the central plant in just 60 days.

General Motors

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In 2004 General Motors selected GHAFARI Associates, LLC to plan and engineer a series of projects. Its first project was the 4 million-square-foot Lansing Delta Township Assembly Complex. Its second was the General Motors Flint Global V6 Engine Plant. The third project, scheduled to be in production in late 2008, is an expansion of the General Motors Toledo Ohio transmission plant. In all of these projects, GHAFARI was able to build on an existing Bentley factories solution to meet new challenges.

Before it could begin planning for the Lansing Delta Township Assembly Complex, GHAFARI Associates had to establish communications for its team at the firm's headquarters in Dearborn, Mich. It faced a two-fold problem: how to provide the non-GHAFARI team members with access to its home office networks while enabling them to work with GHAFARI employees on the same DGN files. To meet the inherent logistical and security problems of such a system, GHAFARI deployed Bentley's ProjectWise collaboration system. An application server in Dearborn served as the main access point for all teams, and a series of remote file storage, connection, and web servers hosted project files in remote locations. Use of the ProjectWise servers was a key factor in the success of the project. The team was able to share the latest information and to minimize the chances of re-work due to the use of obsolete versions of the design documents.

For the General Motors Flint Global V6 Engine Plant project, GHAFARI Associates faced a deadline that couldn't slip. The steel mill order for 4,500 tons of steel had to be placed only three weeks after the start of design; otherwise, the project would have missed the mill rolling cycle, delaying the steel delivery by six weeks. The design team and the fabricator agreed to utilize intelligent 3D model exchange. GHAFARI's 3D analysis model, produced with Bentley's RAM Structural System and RAM Advanse, was transmitted directly to the steel fabricator. The steel mill order was placed in record time and without conventional 2D drawings. The key mill order date of three weeks from the start of design was met, and the fabricator was able to start the detailing process early.

Additionally, the design/build team agreed that it would not be possible to adequately support the engine plant construction schedule if conventional 2D steel shop drawings review was used. Instead, they opted for a 3D-enabled shop drawing review process,

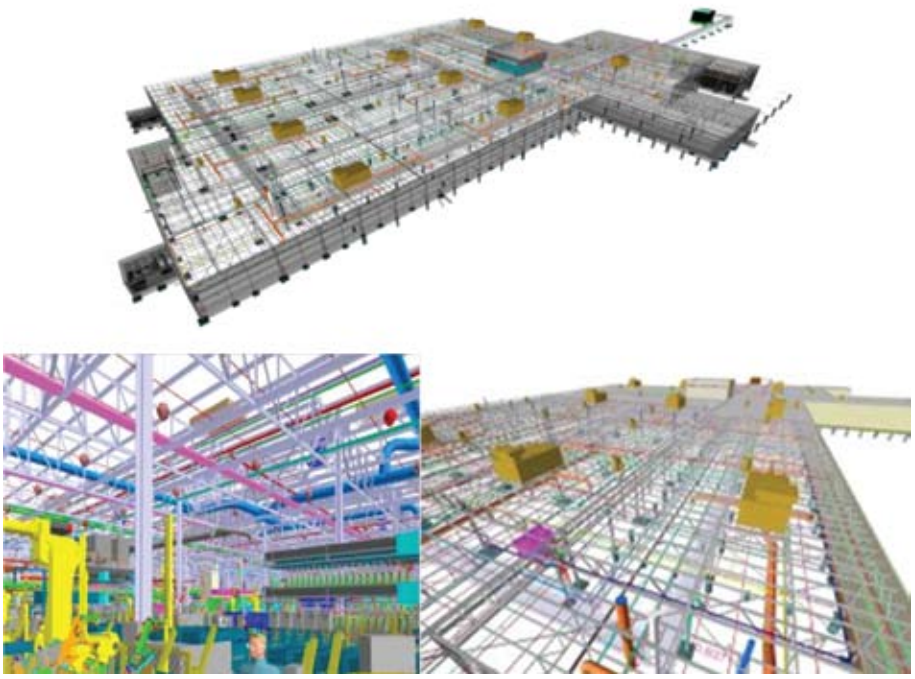

Figure 6: The General Motors Flint Global V6 engine plant designed by GHAFARI Associates. Design and construction of the 417,000-square-foot facility was completed almost five weeks early and with zero change orders, due to increased coordination.

The conventional wisdom of "first in takes the space" did not apply, as the 3D model took into account space requirements of systems that were yet to be installed.

where GHAFARI would receive detailed 3D models from the steel detailers and electronically review and approve the models. The review comments were recorded on the 3D detailed steel members and transmitted back to the detailers to automatically incorporate into the steel detailed models. This process allowed the team to detail, review, and approve the steel 3D models in record time, with less than a two-day turn-around for each submittal. The team avoided producing and handling thousands of 2D steel shop drawings and relied entirely on the 3D model exchange. The final 3D models were fully detailed to installation level, which allowed the subcontractors to maximize the benefits of off-site fabrication and preassembly. By delivering just-in-time to the construction site, the time spent at the construction site was significantly reduced.

Field crews were instructed to install all systems according to the 3D models and associated construction documents. At times during installation, crews had to trust the model, as they were required to install systems with many offsets when there were no other systems around. The conventional wisdom of "first in takes the space" did not apply, as the 3D model took into account space requirements of systems that were yet to be installed. The project was delivered almost five weeks ahead of schedule with virtually no field overtime.

The Bentley Factories Solution Going Forward

Today, Bentley's factories solution users employ a combination of Bentley's own 3D modeling tools and third-party applications. Conveying systems, for example, are

planned with MicroStation plus an application from another developer. For the future, Bentley envisions a full suite of applications specifically dedicated to the design and engineering of automotive manufacturing facilities. To close the gaps in the factories solution, Bentley plans to integrate the systems for planning and maintaining the factory itself with the systems used to plan and maintain the manufacturing processes. This will make it possible for planners in these now-separate workflows to avoid work duplication by sharing objects, models, and other content common to both. Bentley's ultimate objective is to assure that the data created throughout the planning and construction phases becomes an asset throughout the facility lifecycle.

The Bentley factories solution includes a comprehensive set of modeling and engineering applications for creating and maintaining a 3D model of the complete factory building project. The use of a common foundation technology and intelligent interfaces unites the planning and construction workflow, enables team collaboration, and automates the publication of drawings and documents at all stages of the project. Thus, planners are able to complete the design phases of their projects faster and with optimized quality. Construction can proceed on or even ahead of schedule, without costly delays due to errors in design, delivery of the wrong supplies, or inadequately informed construction crews. The sooner the facility is completed, the sooner a liability – the unfinished facility – becomes a profit-generating asset.

The Bentley factories solution includes a comprehensive set of modeling and engineering applications for creating and maintaining a 3D model of the complete factory building project.

Time to market and construction costs can be further reduced though the use of ConstructSim software for construction simulation. ConstructSim models the construction process and provides a construction management environment that links data from design deliverables, schematics, project management, materials, and resource management systems in a virtual and visual model. This linked model allows users to create and track work packages that closely match the actual construction workflow, enabling project managers to more quickly identify issues with time-critical activities or incorrect materials and avoid costly mistakes, schedule overruns, and change orders. This unique "work-facing" orientation of ConstructSim provides an ideal tool for the construction project superintendent or field crew supervisor to organize, manage, schedule, and record the progress of actual installation processes and tasks.

In the near future, Bentley will integrate ConstructSim with ProjectWise Navigator platform and comprehensive portfolio of applications and collaboration servers. This will accelerate integrated project delivery for infrastructure projects by closing gaps between design, construction, and operations.

As their experience illustrates, Bentley's automotive manufacturing clients have implemented the digital factory solution with notable success, demonstrating that Bentley's vision is grounded on solid technical achievements. Bentley's factories solution of the future will be capable of handling every possible workflow variation, including many different subtasks linked into a workflow that covers the lifecycle of the factory. Bentley is delivering on the automotive industry's vision with its factories solution.