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WHITE PAPER

THE VALUE OF LEAN CONSTRUCTION

HOW TECHNOLOGY OPTIMIZES CONSTRUCTION PLANNING AND EXECUTION FOR MAXIMIZED PROFITS

CONTENTS

1. HOW THE CONSTRUCTION INDUSTRY STRUGGLES

The engineering construction industry struggles with making informed decisions based on the most accurate information available and with managing people and materials in a dynamic construction environment.

In many cases, executing a given construction task as it was planned is a challenge. It is often not clear what has to be done, when it has to be done, by whom, and which materials are available. The traditional answer to such challenges is for contractors to include a significant amount of contingencies in their cost estimates to ensure that a contract will pay as much as possible. Typically, less attention is being spent on reducing inefficiencies, risk, and waste at the construction site.

- **Construction readiness**: This has a major impact on a project's budget and schedule. If projects are planned too late or inaccurately, there will be major cost overruns. For effective construction readiness, a similar project vision must be shared by engineering, procurement, scheduling, and project controls.
- **Productivity loss**: The construction industry is muddling through some alarming realities. Only 33% of all work-hours is productively spent for direct work, and 35% is spent on materials, tools, transportation, instructions, and personal breaks; 32 is wasted, spent idle, or waiting due to a lag in materials or information delivery. Every year, owner operators, engineering, procurement and construction companies and contractors are hit with billions of dollars in construction claims as a result of inefficiency factors. Good construction planning should consider and track labor factors in the original work scope. This is to accurately reflect all the conditions that were used to estimate and fund the project, as well as to eliminate or minimize the impact on productivity, which will directly affect the construction costs. It should also include changes in work scope that look at labor impacts as part of the sequence and planning of any work.
- **Lack of supply chain integration**: In today's complex, joint venture projects, EPCs often use high-end design systems for plants. There is an extensive amount of detailed data to share with a variety of stakeholders. Ineffective management of data and supply chain management can result in significant cost blow-outs and delays in project completion. Construction supply chains tend to include a lot of waste.
- **Risk management**: Construction projects can be extremely complex and fraught with uncertainty, which can potentially have damaging consequences. Therefore, risk analysis and management continue to be major features of the project management to deal effectively with uncertainty and unexpected events and to achieve project success*.

It is often mentioned that the solution to these challenges is to become "lean." The term "lean" is usually associated with lean manufacturing, lean thinking, lean production, and lean construction. There are many arguments on what each of these have in common and what their differentiators are. **So, what does "lean" really mean?**

"Lean" has many meanings and uses. It refers to continuous improvement and change management. It is a management philosophy and it relates to minimizing and eliminating waste. However, it is not what is eliminated, but added, that is the most defining denominator: **Value**.

To clarify, being "lean" is not about cutting costs or resources or trying to get maximum results out of the minimum input. Nor is it just about decreasing inefficiency. **It is about providing the most value possible.**

1.1 A SHIFT IN THE CONSTRUCTION PARADIGM

Also, in the construction industry, we have seen a shift in the construction paradigm with a focus on “lean construction.” Lean construction is a combination of operational research and practical developments in design and construction with an adaption of lean manufacturing principles and practices to the end-to-end design and construction process. In addition, the basic principles of lean construction supplement the basics constructs of Advanced Work Packaging, the latest best practice from the Construction Industry Institute (CII).

The concept of “lean construction” is more than just a set of tools; it represents a new way of thinking and is about people and processes that come together to diminish, if not eliminate, the non-value-added aspects of doing business. The focus is on change management and waste reduction, in all its forms, with hands-on involvement and long-term vision, all of which will allow the industry to excel in the long run.**

When we mention waste, we refer to items such as waiting time, surplus materials, unnecessary transportation, bureaucracy, underuse of resource potential, hidden and late delivery of information, and anything else that does not add value to a process. It also includes losses in data integrity of both engineering and procurement information, which needs to be available to the construction team.

To summarize, by reading this white paper you will:

- Learn what the concept of “lean construction” includes and how you can use those principles to add more value to your organization and increase your profitability
- Discover how technology is advancing to make the implementation of lean construction practices possible to both your company and the whole industry
- Understand how crucial it is to integrate “lean” with technology and how you can use tools that support the shift in the construction paradigm delivering maximum value and to develop a sustainable future

2. THE ORIGINS OF LEAN CONSTRUCTION

Toyota was the first – or at least the most notable – organization to bring “lean principles” into the limelight. In the 1970s, Toyota created a focus on eliminating waste to improve customer value in the automotive industry. The small Japanese automaker grew to be the world’s largest by adopting seven waste reduction principles in its production manufacturing and preserving value with less work.

The philosophy of focusing on waste elimination was expanded to include improved efficiency by optimizing workflows and came to be known as “lean manufacturing.” Today, lean manufacturing is practiced by most of the major manufacturing companies worldwide and has greatly influenced other industries to adopt “lean” policies, including the construction industry. This said, the term “lean construction” was adopted nearly 20 years ago and is still trying to gain momentum in the construction mainstream.

Looking back at the evolution of the construction paradigm, the original key points of attention were cost and schedule. The primary goal was to get projects done fast and cheap, often at the expense of one or the other. As times changed, however, regulatory and humanitarian pressures made safety a new project driver, escalating the safety of workers and efficient processes to top priority. It was thought that this shift would bring extra costs and delays. However as new safety standards were implemented, contractors saw a reduction in accidents, lower insurance costs, and a decline in workers’ compensation, with

productivity back to previous levels and later increasing. Owner operators and contractors realized that safety mitigation was an added investment in time, money, and resources, but it also saved time and money. Enforcement was a smart idea because it produced a great return on the investment required: It had value.

The same was true for quality. Poor quality caused customer dissatisfaction through rework, delays, and cost overruns. Investments in quality assurance programs, people, systems, and controls improved workflows and added value.

Lean construction is a new paradigm in construction planning that uses lean concepts that approach value rather than cost, and efficiency rather than schedule.

Lean Construction, as defined by the non-profit Lean Construction Institute (LCI), is a production management-based project delivery system, emphasizing the reliable and speedy delivery of value. The goal is to build the project while maximizing value, minimizing waste, and pursuing perfection – for the benefit of all project stakeholders.

Lauren Pinch, Construction Executive, November 2005

Owner operators are the main stakeholders in construction projects, and it would be remiss not to recognize that cost, schedule, quality, and safety are the key drivers behind their project approval and funding. However, to truly capitalize on the concept of lean construction, all stakeholders must support the overall lean philosophy of decreasing waste, which inherently increases the "value" of the process.

Waste comes in many forms, some unexpected within the traditional construction paradigm. They include unnecessary transport or motion, waiting, inventory, defects, over-processing, over-production, and defects. *** This is a comprehensive list that demands high level stakeholder engagement and understanding of how each potentially wasteful task impacts the value and productivity of a construction project.

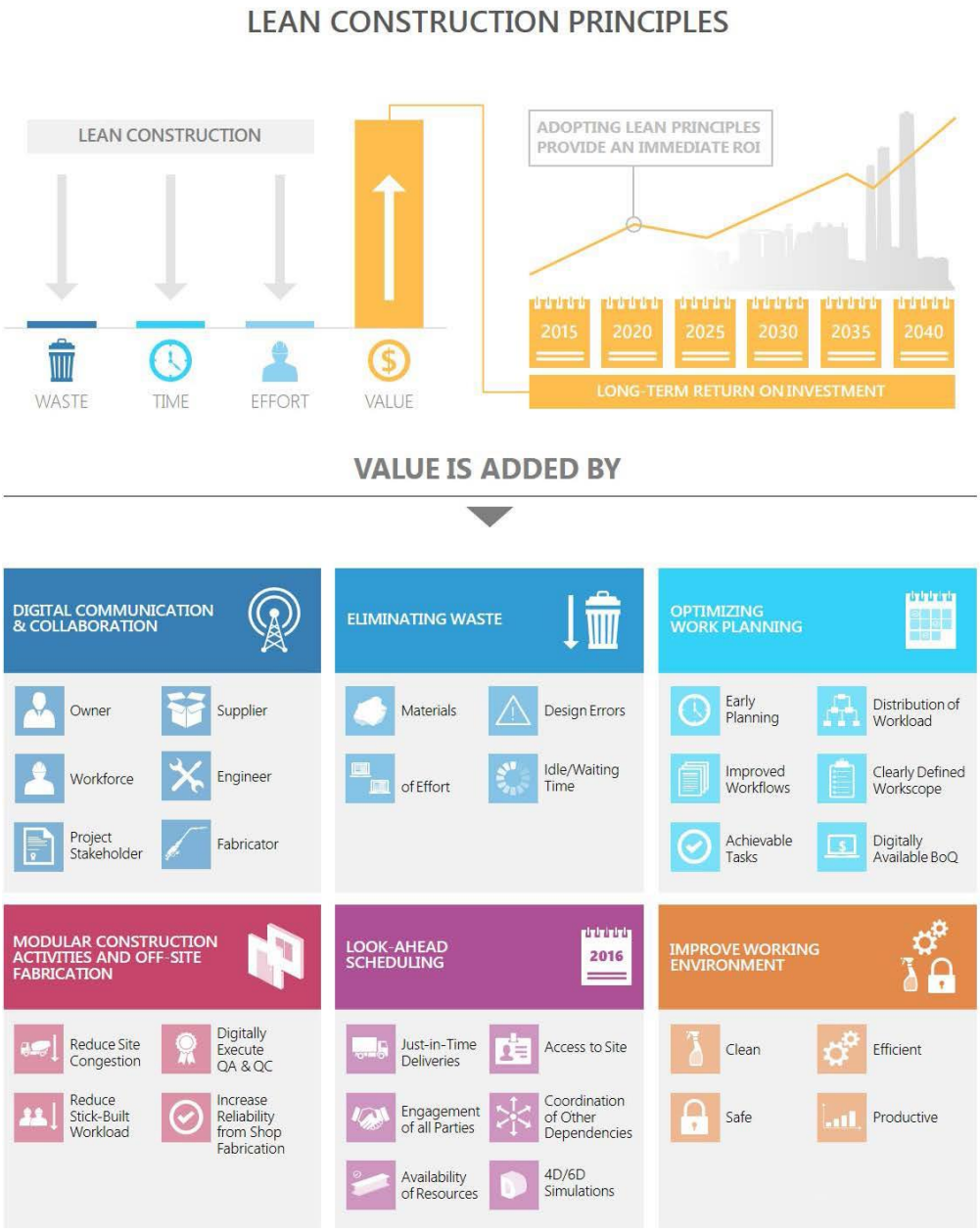
The best way to achieve that value is to incorporate lean practices into early planning before the project is approved. Collaboration must be achieved with the owner operators; engineering, procurement, and construction companies and all project participants to build these lean principles in the conceptual stage as early as possible.

Introducing lean philosophies and reduction of wasteful processes early on may, however, require a significant focus on change management. Although few would argue with the results of lean construction – that is, more productive and profitable projects – many traditional work processes and project methods are engrained in the slow-to-shift construction industry. All stakeholders involved will have to buy into this new, smart way of thinking and make changes to their (often comfortable) ways of working and processes, in order to achieve the benefits of lean thinking.

3. HOW LEAN CONSTRUCTION ADDS VALUE

Lean construction is a "way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value. ****"

Value in construction is like value in any business: It is a return on your investment. Adopting lean principles is an investment in the future of the project, which will reap benefits and give a solid return on investment.



4. THE CRUCIAL ROLE OF TECHNOLOGY

Computers have played a key role in improving project performance for many years by increasing the speed, accuracy, and quantity of data that can be processed. However, most of the people on-site are still suffering since computers are not enough to make your processes leaner. In addition, **smart technology** needs to be adopted, on a wider scale.

But what is smart technology? When we say this, we refer to technology that records all data into open, standard, and commercially available databases which are used to execute all business work processes. It means, for example, that engineers and other project stakeholders no longer need to struggle with managing files, dealing with proprietary database formats, or integrating with third party or legacy systems.

This “digital data-centric” approach to design brings a variety of benefits to the value chain and its stakeholders:

- It allows **Objects Correlation**, which is the ability to digitally recognize design objects in the system and automatically understand how they work together. It has two important implications, both bringing value and efficiency to project stakeholders:
    1. Multi-discipline coordinated consistency: As soon as all the data describing given objects are in the standard database, the system can recognize whether a component[1] in the project is the same among several tools. This is a key feature to maintain and reuse consistent information across different disciplines and functions.
    2. Multiple objects design change implication: As soon as a design change has to be executed on a given component, the database will know and point out which objects will be impacted, supporting the 3D designer accordingly. Hence, a better, more accurate design solution can be achieved with just a few clicks.
- It enables **Work Sharing** on a global basis. Timely visual status updates are provided on what other disciplines, operating centers, and eventually engineering partners or subcontractors are doing, therefore maximizing cooperation and collaboration among all stakeholders. It works in

[1] Component is any physical object having a virtual representation in 3D, e.g. either a long lead equipment, or a valve or piping line.

real time, enables a huge productivity increase of liaison engineers, and massively reduces coordination costs.

- It allows **Automation**. All project information is available in the standard databases, so it becomes possible to process it further and apply design rules and verification checks resulting in increase in both quality and efficiency. With such an approach, typical engineering design tasks are all automatic outputs of system data processing: creating drawings, defining requisitions for purchasing materials, forecasting construction execution upon site materials availability, etc. The consequence? No more error-prone manual executions and a huge decrease in verification costs.
- It provides real time **Change Tracking and Management**, which is key in developing detailed design, especially with today's fast track projects. Some key enabling features are the following:
    1. The ability to record each digital version of the same document and automatically compare them
    2. Highlighting differences in material requirements among various project statuses and phases
    3. Receiving system notifications about deliverables reflecting a design change, which needs to be released with a higher revision number. This is fundamental information that needs to be available timely to the construction companies.
- It allows so-called **Surplus and Shortages Free** execution, meaning that "just in time" delivery of materials at the construction site is possible. This is driven by the digital execution of engineering to procurement work processes. This is also driven by relevant change management from one side and data-centric supply chain management with accurate and timely information provided to construction stakeholders on the other side.
- The goal is to prevent shortages before a planned erection or installation. Using surplus and shortages free principles, one can avoid expensive last-minute purchases of missing components and prevent claims from construction subcontractors. However, one can also avoid surplus and excess materials delivery and save costs for handling and storing such excess materials.
- It ensures **Tag Number Consistency**. This is the result of applying digital rule-based naming conventions. It enables the reuse of equipment or instruments relevant properties across the engineering and supply chain, down to site construction. No more inconsistent designs.
- It allows **Reuse, Simulate, and Look Ahead**, meaning that the engineering output and design tasks, 3D, and relevant deliverables can be immediately reused to feed constructability analysis and construction design review sessions. Because of this, construction stakeholders join the project earlier than ever. Furthermore, enhanced visualization triggers additional benefits like preventing potential construction issues when on-site and enabling more accurate construction planning so that animation can simulate different approaches to construction execution. This would happen before a plan would be adopted. The digital acknowledgement of the so-called Engineering Construction Quantity eliminates the need for a lengthy, costly document-based engineering to construction handover process.
- It allows **Capturing Real Assets**, with real dimensions, so that a complete digital model can be created reusing existing elements as a source for defining new virtual assets. At the same time, it enables new digitally-based certifications and quality control / quality assurance work processes for comparing erected assemblies, manufacturing parts, modules, etc. One can use a relevant digital view from the 3D model to digitally determine deviations and match tolerances.
- Smart technology based on a standard database allows an easy **handover** of this huge and valuable set of engineering and design data to operations & maintenance, which ensures that plant lifecycle management is based on accurate information.

Smart technology is the main mean to improve efficiency and eliminate waste in any discipline and relevant cross functional collaboration. The use of smart technology advances lean construction in any organization.

5. SMART TECHNOLOGY FOR LEAN CONSTRUCTION

The construction industry has to deal with the major challenge of proper planning. In the previous chapter, we explained the crucial role of technology and the beneficial use of Smart technology and its data-centric approach for the successful completion of construction projects. Smart technology is the main mean to improve efficiency and eliminate waste in any discipline – it makes you lean.

Effective construction management requires accurate information and a stronger connection to available data and those who use that data to initiate and complete the construction process. Integration with materials management is crucial so materials arrive on-site on time. There must be easy, fast, and accurate reporting; there is no need to reinvent the wheel. Simply set the construction environment once to evaluate progress, interact with crews and contractors, and identify performance to control costs. Accurate information is needed prior to initiation and is essential for forecasting and ensuring the vast amounts of project data are in sync, allowing those managing materials, engineering, and planning to make informed, fast decisions if changes are needed.

It all starts with the ability to smoothly integrate all disparate data that construction planners and foremen require in one single platform, such as:

- Construction master schedule
- Drawings and documents
- 3D models
- Materials requirements

This way, all information will be available from inside the package, and planners will have the ability to execute with informative, appropriate decisions. It will also allow construction planners to provide the team in the field with accurate information to execute their tasks.

5.1 A NEW METHOD FOR CONSTRUCTION PLANNING

Hexagon PPM's Intergraph Smart® Construction has been developed to meet the specific needs of construction companies, project management offices, fabricators, and owners in managing construction resources, materials, and schedules.

The intuitive, configurable interfaces enable work package planners to create effective work packages using industry-proven work processes. Real-time material integration availability reports provide dynamic re-planning capabilities, and a configurable planning window enables planners to make economical modifications before problems grow.

5.2 ENHANCING OVERALL EFFICIENCY

Hexagon PPM created Smart Construction specifically for construction planners to more efficiently plan and manage fabrication and construction projects, resulting in enhanced safety, increased quality, and improved productivity.

5.3 VALIDATING CONSTRUCTION DECISIONS

Using current information from various sources such as 3D models, 2D engineering tools, materials management, and project control and scheduling systems, Smart Construction ensures accurate and timely decisions can be made on the best available information. You can create 3D models and drawing filters with enhanced 4D animation, powerful new pre-configured filters, and selection rules for a 3D model. This delivers you significant efficiency and improvements in building a work package, along with cost and time savings.

5.4 REDUCING CONSTRUCTION RISKS

Construction projects are extremely complex to manage. Risk and uncertainty are negatively influencing, making risk analysis and management critical for successfully managing them.

To be able to deal effectively with uncertainty, Smart Construction offers an integrated solution, linking the engineering vision with materials availability supply chain, project cost, progress, and scheduling. The advantage of having true data integration and a single source of truth benefits the entire engineering, construction, and operations value chain:

- **Owner Operators** can improve their CAPEX efficiency by forcing contractors to use the latest technology, making them strive to prevent waste, and therefore benefit from reduced costs.
- **Fabricators** will benefit from improved fabrication planning as they reuse engineering information provided in its native format without the need to manipulate it further. This improves efficiency and makes the whole process more reliable and cost effective.
- **Constructors** can reduce project cost with improved visibility on project plans, accelerate their ability to re-plan in response to real-world changes, and take advantage of enhanced integration with engineering, procurement, and fabrication to optimize both engineering and construction decisions.
- **Project Management Contractors** will benefit from having sub-contractors who maximize their ability to deliver construction execution in a very predictable manner.

6. INCREASE VALUE WITH SMART CONSTRUCTION

6.1 OPTIMIZED WORK PLANNING SAVES COSTS AND IMPROVES COLLABORATION

For successful construction projects, you need to optimize your work planning. The software allows you to plan earlier and to improve workflows, sharing the right information with the right people at the right time in the right format. It provides you with digitally available Bills of Quantities, it helps to define achievable tasks and a clearly defined work scope, allowing you to optimize the distribution of the workload.

6.1.1. Work Package Planning

Smart Construction can be employed to provide visual representations of work packages – detail-level descriptions of construction work that a foreman and a crew can perform in a scheduled amount of time – with engineering, construction, and design data stored in a database. Users are also able to view, navigate, and filter 3D models and 2D drawings that were published to the database.

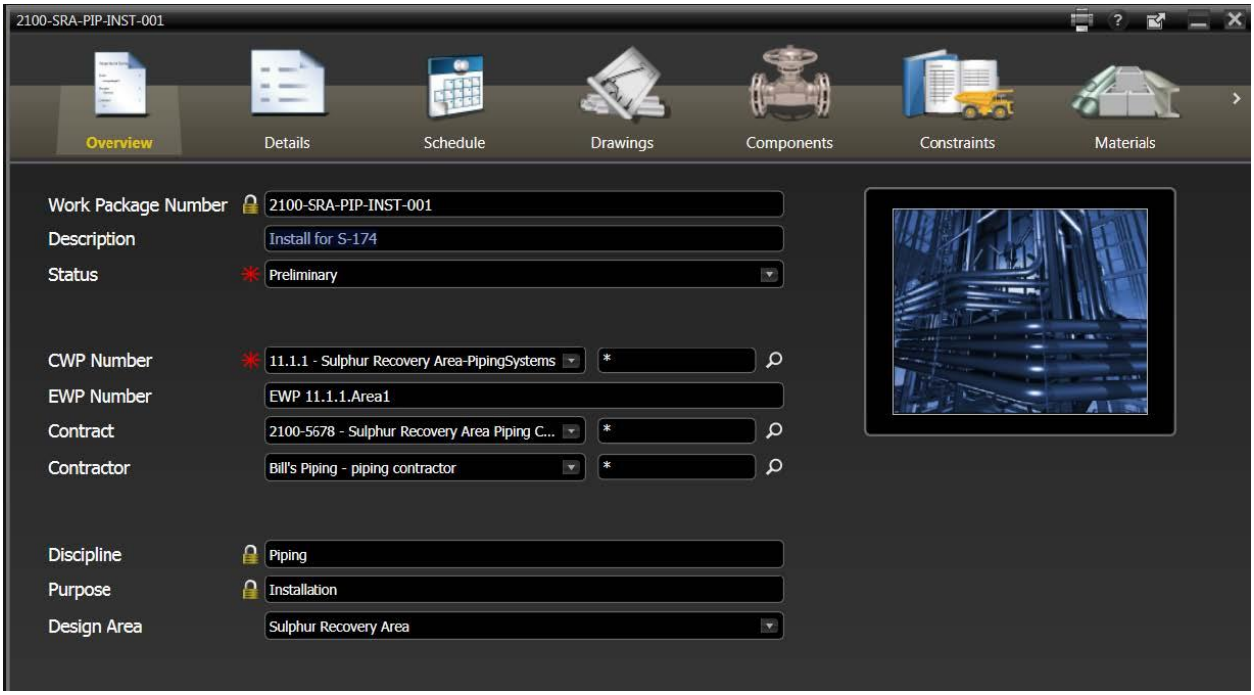


Figure 1: A picture is displayed to identify the work package by discipline.

6.1.2. The Sharing of Information

The Smart Construction workflow allows users to digitally share accurate engineering, construction, and design data among engineering products and users. Smart Construction is configured to provide a comprehensive electronic data storage, exchange, management, and integration system.

An open API provides direct integration with other non-Intergraph applications, such as material, project control, or schedule systems.

The workflow process allows the following:

- 3D design and construction planning can work together to make delivery, support transparency, and maximize value
- Engineering, drawings, materials, schedule, and planning are linked “real-time” to improve performance and monitor results
- Reconfiguring project specific value chains for optimized supply chain integration
- Work packages created using work breakdown structure (WBS), as illustrated below in Figures 2 and 3
- International communication illustrated below in Figure 4

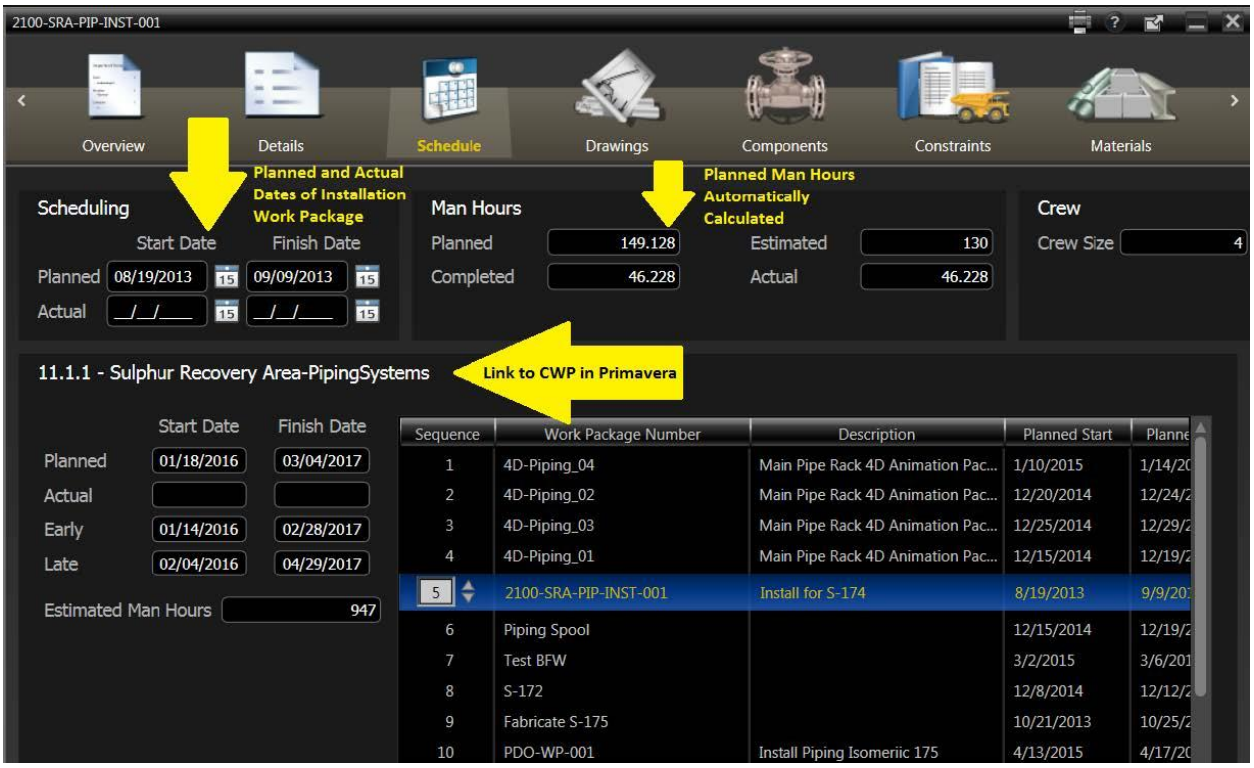


Figure 2: Smart Construction enables work packages to be created and linked for a clear workflow.

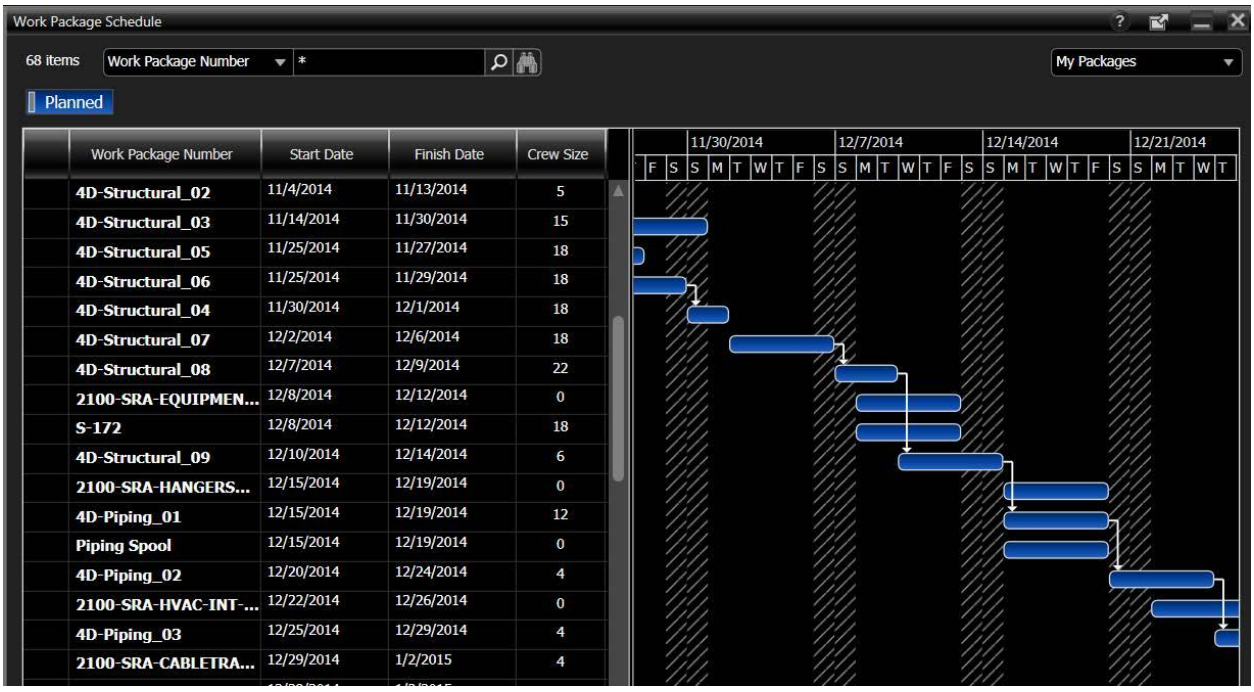


Figure 3: Smart Construction enables Work Package Schedule Optimization

Today, we have suppliers, engineers, contractors, subcontractors, and projects around the world. The need for strong communication in a common language is greater than ever. With improved technology, visualization is the strongest form of communication breaching the international language barrier; however, the written word is still relied upon in certain instances. As illustrated below in Figure 4, Smart Construction enables a homogenous or heterogeneous environment, allowing regional settings to be changed to multiple languages, such as Chinese, Russian, Portuguese, or other languages, which can be viewed simultaneously around the world. This eliminates problems, errors, and wasted time caused by misinterpretation or failure in communication that breaks the workflow.

Figure 4: Smart Construction is available in multiple languages.

6.1.3. Visualization

We retain 10 times more information visually than through written instructions. Increased visualization communicates key information to the workplace in which it will be retained. Workers not only remember the workflow and other key elements but are also confident in executing as a result. Figure 5 below is an example of a 3D model for increased visualization.

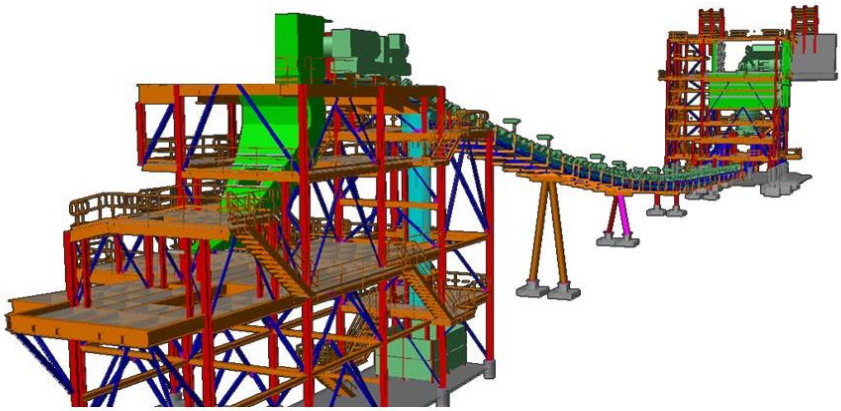


Figure 5: This 3D model helps to increase visualization.

Take “snapshots” in the 3D model to visually communicate workflow, show constructability, or flag workplace hazards. Visually show workers areas of the project to avoid or annotate those snapshots (as illustrated below in Figure 5) with notes of caution such as “handrails that are not welded,” “access that is closed,” or other instructions.

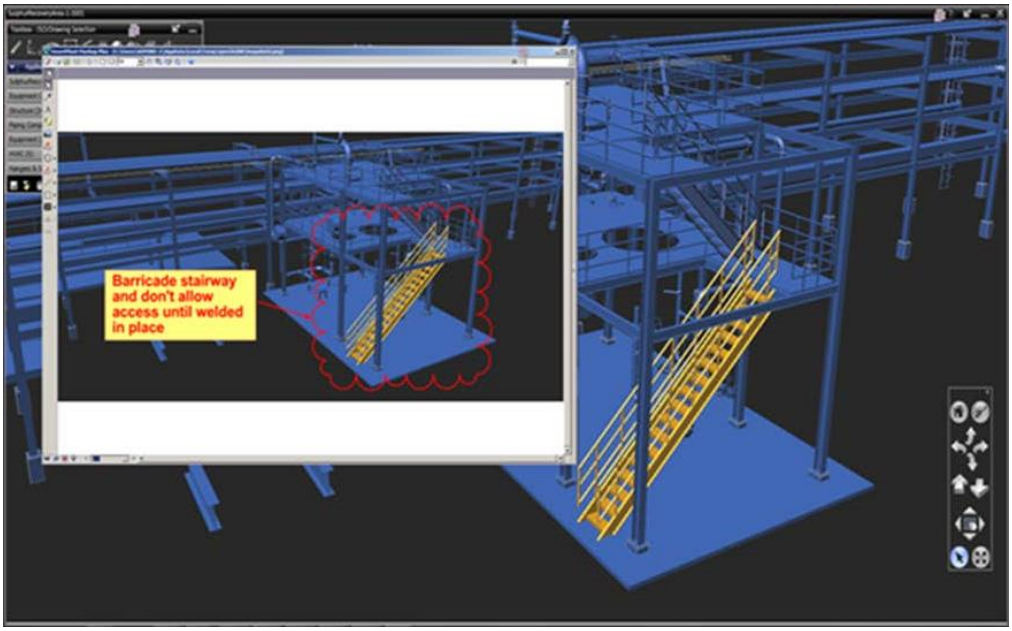


Figure 5: Smart Construction enhances the safety of a project through visualization for clear safety communication.

6.2 LOOK-AHEAD SCHEDULING INCREASES EFFICIENCY

When construction planners constantly focus on the end date, they lose sight of the current opportunity for improvement by focusing the work taking place in the next few weeks. Lean construction planners think smart, and do not lose the opportunity to view workflow opportunities for improvement. A “look-ahead schedule” allows the work planner to see work packages scheduled to start in the next few weeks and enables planners to efficiently prepare and communicate workflow processes, just-in-time deliveries, and resources to the work force. This facilitates engagement with others and coordination of dependencies.

As shown in Figure 6, our solution will filter work packages to provide a standard out-of-the-box, look-ahead schedule selection for work scheduled in the next week, three weeks, or eight weeks. It also provides controls allowing planners to see work packages planned for selected start and finish dates with an adjustable sliding date control. Planners can see all work packages within a selected range of dates.

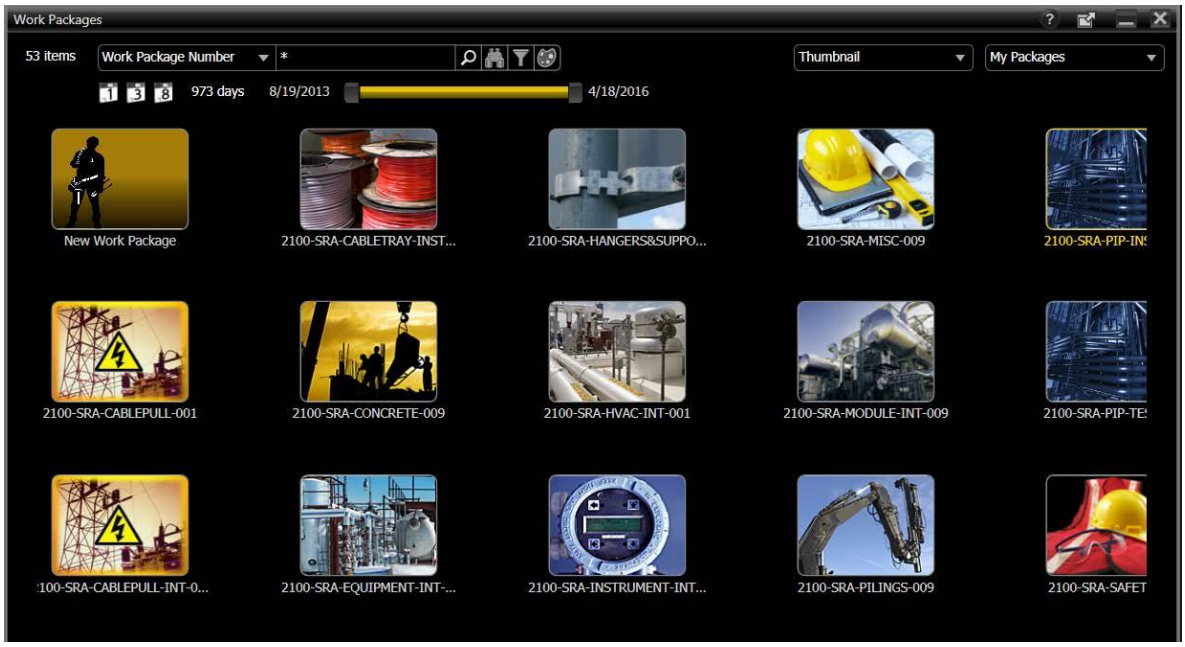


Figure 6: Smart Construction enables look-ahead scheduling for work packages.

Work planners create a work package and assign sequenced work steps and components, which are then linked to the WBS schedule and material management system. Work packages can be reviewed in the look-ahead schedule and animated in the 3D model to verify if conflicts, resources, or constraints prohibit planned execution. It can also help illustrate if adjustments are needed to maximize efficiency.

6.2.1. Just-in-time Deliveries

Figure 7 illustrates how work planners can view material forecasts and make reservations directly from Smart Construction. Material availability can be sorted by tag number, drawing, or commodity code. Material location and estimated time of arrival are known in “real-time,” with direct links between the

material management system, schedule, and Smart Construction to enable “just-in-time” deliveries. This eliminates waste and shrinkage and prevents delays.

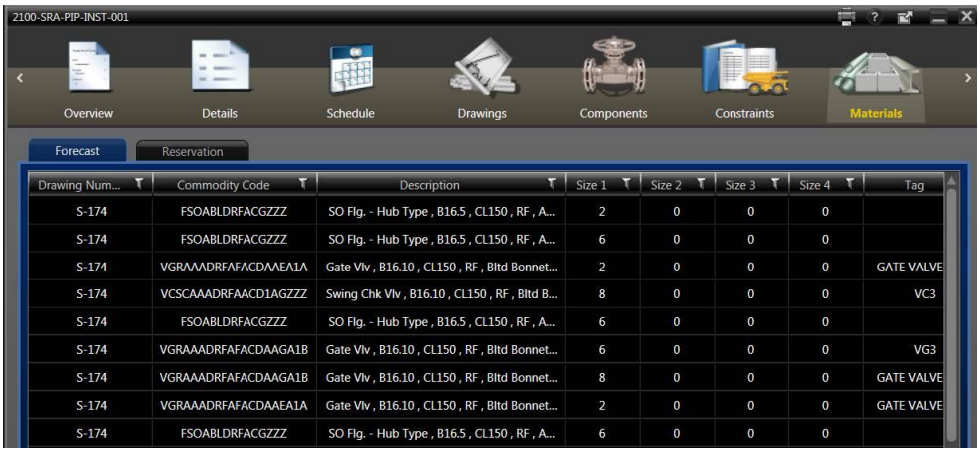


Figure 7: Smart Construction enables work planners to view material forecast and make reservations directly for just-in-time deliveries

6.2.2. Animation in 4D – ‘What-if’

The ability to animate the construction workflow allows work planners to identify conflicts and correct them before errors or delays occur (illustrated in Figure 8). It also helps visualize the constructability of the project and communicate the workflow process, site access, and animates the work sequencing and schedule. As the saying goes, “a picture paints a thousand words,” and the 4D animation is able to communicate what needs to be built and where.

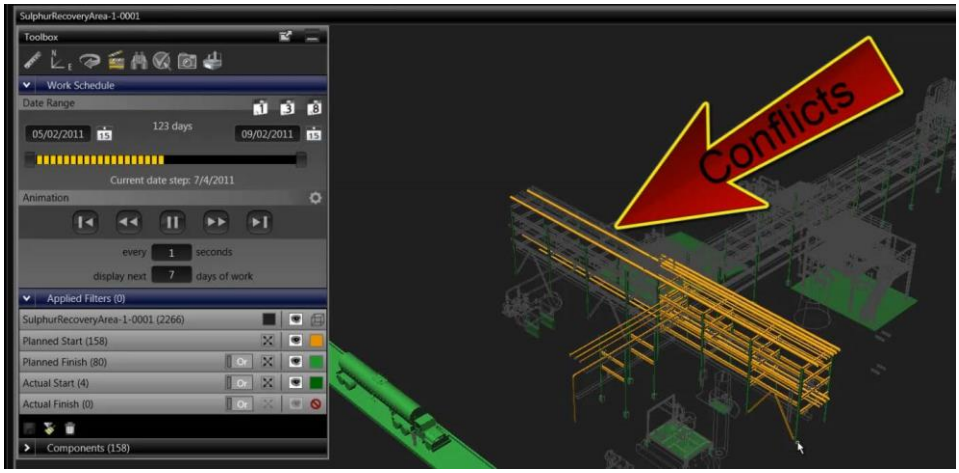


Figure 8: Smart Construction features enhanced 4D animation, enabling work planners to identify and correct conflicts early in the planning process.

You will also be able to adjust variables and visualize totally new scenarios and see the impact on the plan before it happens. This maximizes value, making construction both safer and more efficient. As delivery times shift, vendors send information onto the shared system and the impact can be clearly seen, allowing for a solution to be worked out. If materials do not arrive at a particular site, the workers know that a certain work package cannot be completed, so they can then consult the model and look to see if

parts are available elsewhere on the site to help them complete the job. Construction people will know what is onsite, what can be built, and when future deliveries will arrive.

6.2 MODULAR CONSTRUCTION FOR INCREASED PRODUCTIVITY

The ability to create modular designs in 3D and develop work packages to manage these allows for increasing offsite work and brings value to construction planning. As shown below in Figure 9, Smart Construction enables modular construction, and the user is able to manage the work packages for those specific modules. Modular construction is usually performed in controlled environments with lower labor rates that are highly productive and can be staged and sequenced for just-in-time deliveries, eliminating site congestion, reducing site labor, and shortening schedule durations.

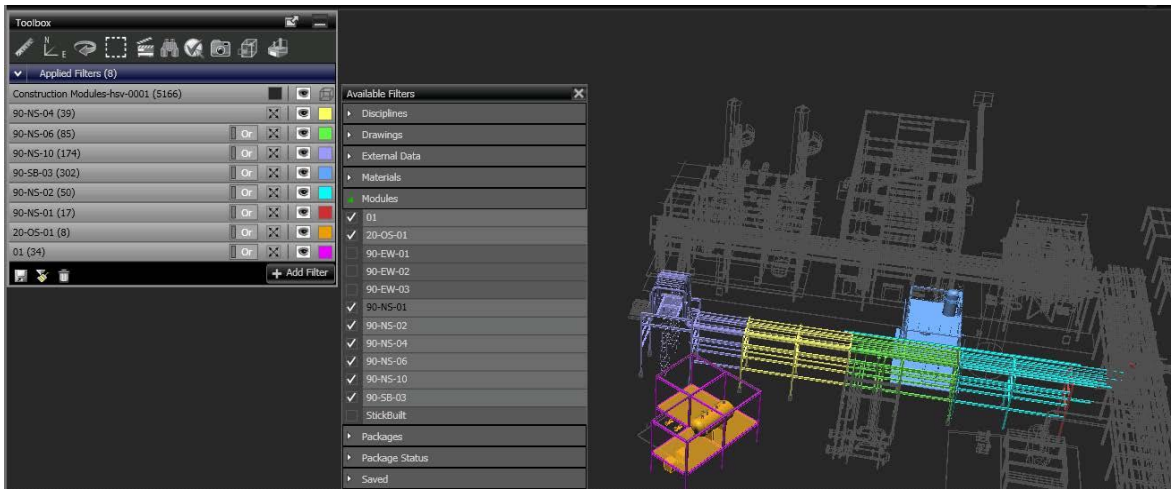


Figure 9: Smart Construction features allow for planning modular construction

7. LEAN CONSTRUCTION: THE FUTURE

Lean construction is gaining momentum in the industry. With a trend towards incorporating lean construction principles into standard work processes, construction planners are now able to make informed decisions. Introducing lean principles into a company will be a challenge to accomplish, but more and more owner operators, EPCs, and their supply chains understand the value of this approach and use it.

The lean approach focuses on getting maximum results out of the minimum input. It is about providing the most value possible, and technology has played a key role in achieving this. However, just the use of computers only is not enough. One needs to take it a step further and introduce Smart Technology as well, which allows for a digital data-centric approach. Using accurate data, a single source of truth, and cultivating collaboration between all stakeholders, it improves construction readiness, reduces risk, and increases productivity.

Smart Construction is the next-generation software that is built with lean principles featured as standard out-of-the-box functionality. It brings advanced technology to the workflow process by putting

"lean" tools directly in the hands of work planners and embedding a lean construction culture directly into the project planning and execution.

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About Hexagon

Hexagon is a global leader in digital solutions that create Autonomous Connected Ecosystems (ACE). Our industry-specific solutions create smart digital realities that improve productivity and quality across manufacturing, infrastructure, safety and mobility applications.

Hexagon's PPM division empowers its clients to transform unstructured information into a smart digital asset to visualize, build and manage structures and facilities of all complexities, ensuring safe and efficient operation throughout the entire lifecycle.

Hexagon (Nasdaq Stockholm: HEXA B) has approximately 20,000 employees in 50 countries and net sales of approximately 3.8bn EUR. Learn more at hexagon.com and follow us @HexagonAB.

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