TOMORROW'S WORKDAY: SPONTANEOUS, CREATIVE, AND RELIABLE

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ABSTRACT: Through several scenarios, this paper shows how a construction project manager might spend a workday in the future. The particular tasks addressed include participating in a design review meeting, preparing the construction input to an engineering issue, tracking the schedule, budget, and environmental performance on a project under construction, dealing with organizational issues around innovative methods, and maintaining the company's intelligent production planning and control system. Through these examples, the paper also tries to show that the combination of lean production methods and virtual design and construction tools should not only lead to reliable workflow, but should also enable and leverage the ingenuity, spontaneity, and creativity of designers, engineers, and builders.

KEYWORDS: virtual design and construction, lean construction, future scenarios.

1 THAI FOOD, ANYONE?

Greg eased his feet into the foot massage device in his car. He reflected on the workday that was winding down. Meanwhile his car was also locating Thai restaurants that were highly rated and where he had not yet eaten as well as friends that were nearby and who might be interested in dinner in the next hour or so. Things had changed quite a bit since the beginning of the 21st century when virtual design and construction, digital prototyping, and lean production methods started to make an impact in engineering and construction practice. Those days seemed like the Wild West now. Not only could he get his feet massaged while driving instead of needing them to speed up and slow down, he could also contribute his expertise and creative ideas to projects in all phases much more productively and with much more spontaneity than possible then. In those days new ideas were often anathema for project managers because all too often new ideas meant that the project scope could not be delivered reliably within the given schedule and budget. Therefore, it was not uncommon for clients to receive completed facilities later than expected with less functionality than could have been possible at a higher cost than budgeted. Furthermore, buildings were a major contributor to the high CO_2 emissions and other pollution that plagued the planet. Since then, computer-based modeling, simulation, analysis, visualization, and collaboration methods sure had made a difference because he could evaluate more options more quickly and comprehensively than anybody thought possible at the time.

He had just left a design review meeting for a new school. Compared to the Wild West days this meeting had been dramatically more productive. 95% of the meeting time had been focused on the most important project issues. Many more issues than possible before were covered in one hour, with 90% of the issues resolved during the meeting. This was possible because 100% of the stakeholders that needed to participate in the design review were present to review the 52 design options – some in their fifth version – against the 22 most important life cycle design criteria and compare the proposed designs against twelve recent projects with a similar scope and evaluation criteria. It was also possible because this review meeting had been well planned in the context of the entire project to resolve the critical issues that would unlock the next phase and level of detail in designing the school and its life cycle. The information basis for the decisions that had to be made was sound with 80% of the analyses required for the 22 criteria based on formal, validated models that could be represented, simulated, analyzed, visualized, compared, and coordinated with well-founded computational methods. The priorities for the various stakeholders in terms of the 22 criteria and the impact of each design option on these criteria were transparent. His assignment for the next two days on this project was clear: Greg needed to determine how a new material the structural engineer thought about using for part of the structural system would impact the construction and operations phases. He would need to review the assumptions behind the cost estimating and production planning data he had been given carefully and compare them to the assumptions in their estimating and planning systems, and he would need to obtain and validate the environmental and social performance data from the material manufacturer and other parties in the material's supply chain. These were essential data for the computer simulations he would run to assess the life cycle performance of the material in the context of the structure and determine the cost and management attention needed to incorporate this proposed change into the existing organization and schedule of the project. He wasn't sure whether the potential life cycle benefits would outweigh the cost and efforts to incorporate the new material in the design of the facility and its delivery process and organization, but he would find out soon enough.

2 GREG'S WORKDAY

Throughout the day Greg had participated in an alliance meeting for a new project, prepared the construction input to an engineering issue, tracked the schedule, budget, and environmental performance on a project under construction, dealt with organization issues around innovative methods, and maintained their intelligent production planning and control system.

2.1 *Setting up project alliances*

In the past, the many parties that needed to provide expertise for a project would join a project in a rather sequential fashion. Important expertise for and commitment to a course of action would often not be available until late in a project when the time, budget, and will to make changes to a project's design to improve its life cycle performance had all but vanished. Fast track was a preferred method to orchestrate projects. Fast track provided the illusion that owners could decide late on important features of a facility to take advantage of new technologies, e.g., a better medical device, or to address market opportunities, e.g., strong demand for a particular product, but could still open the facility early enough to enhance their market position. While fast track worked sometimes it often also led to large budget and schedule overruns and missed opportunities from the early, consistent, and constant holistic consideration of important facility life cycle concerns that was now the norm. It took a few years for owners and their design, construction, and facility management service providers to gain trust in the virtual design and construction process where the facility and its life cycle are built in the computer as often and for as many perspectives as necessary to enable all the important project stakeholders to make reliable commitments. As more and more project concerns could be modeled with computer-based methods it became increasingly possible and necessary to engage the stakeholders that were in a position to commit to a specific life cycle performance during the design phase of a project to fully leverage the benefits of building and using a facility digitally first. At the alliance meeting, the key team members had agreed on the important elements of the new building, which was critical to enable a creative and focused multi-disciplinary conceptual design process. The important functional requirements had also been reviewed and described formally, and the team had agreed on how to predict the expected performance of a proposed design against these requirements. Finally, systems and responsibilities for information management and communication were established.

2.2 *Multi-disciplinary, concurrent conceptual design*

First thing in the morning, he had participated in a conceptual design review session. The owner of a health care facility needed to decide how much parking to build and how to build it. Public and private transportation was blending together with autonomous cars becoming more widespread. It was expected that in about five to ten years the amount of parking needed would go down significantly as the number of autonomous vehicles increased, which would then function like a highly flexible public transportation system, sort of like public taxis. Furthermore, the regional master plan showed a mass transit station nearby to be built in about ten years. Therefore, the owner wanted to explore different options for bringing patients and visitors to the facility, including a "temporary" large parking garage with a service life of about ten years with different options for recycling and reusing the components of the structure, a more permanent large parking structure, and a permanent small parking garage coupled with a range of transportation options. The main other participants were the architect, the structural engineer, the energy provider, and, of course, the owner. The main criteria included minimizing monetary life cycle costs, maximizing life cycle energy performance, minimizing CO_2 emissions, minimizing patient and visitor time in the system, and maximizing the productivity of the healthcare staff. Since most comparable data was available for a permanent structure, the permanent structure became the "defending champion" or baseline option. In preparation for this meeting the participants had created 3D building information models for each of the options linked to the processes needed to create and operate each option. Greg had compared the proposed baseline option against ten similar projects the firm had completed recently and developed the analysis method to determine the impact of the construction phase of the options on each performance metric. Greg's staff had combined and coordinated the models and related analyses prior to the meeting, and their performance against the metrics had been predicted through formal computer-based analyses. During the meeting the team

- considered the assumptions that had been made for the various analyses,
- assessed the major uncertainties (such as the likely demand for pre-owned structural components in about five to ten years),
- established the ripple consequences of the various options on other key elements of the facility (such as location and size of the main lobby),
- refined the parking element in the product breakdown structure,
- discussed design strategies, tasks, milestones, and decision points to develop the parking concept further,
- connected the resolution of the parking approach into other key design decisions so that the related tasks and decisions could be managed better, and
- evaluated the impact of each option on the project and owner organizations and processes to establish, e.g., the necessary management capacity and attention for each option.

Because of its positive impact on patient throughput and staff productivity and the relatively good environmental performance due to the potential to reuse the components of the structure, the "temporary" structure looked like the way to go. The team decided to keep the small structure and public transit option open as well.

2.3 *Constructibility input*

Later in the morning he had been asked to provide constructability input on a project that was in early design development. The architect and structural engineer wanted constructability feedback before they finalized the layout of the spaces and structural system. Since the structure of the building was in concrete, he considered the detailing, procurement, and field assembly or construction that would be required for the various options. He considered the potential for prefabrication, the opportunity to work in parallel with other trades or even incorporate some of the work of other trades with the concrete structure, and thought about how future modifications to the building could be made easier with a particular layout and corresponding structural system. He had simulated the life cycle performance of several layout options, structural materials and spans from a construction perspective which enabled him to provide input to the design team on the key parameters that affect the cost and value of a particular building layout.

2.4 *Tracking project performance*

In the afternoon, he spent some time virtually visiting three construction sites to track their performance. He could see the performance of all his jobs on the dashboard "minute-by-minute", but he still liked checking in personally with the sites so that ideas and concerns from the site staff and workers could be addressed quickly. Even as late as 2007 most construction professionals thought that it wasn't feasible and didn't make sense to track field work in great detail and in real time. However, the design-fabricate-assemble method coupled with better traffic management systems that led to more predictable transportation times made components and subassemblies available on site with far greater reliability, higher quality, and lower cost than was thought possible at the time. Now, based on the project's building information model and production steps and data from the company's ERP system, computer tools generated and updated a master list of all tasks that needed to be carried out on a project. Field workers (assemblers) now received instructions from their work straight from the computer-based planning systems linked to the project's master schedule and latest design information. They also documented the work with pictures that were automatically indexed by time and location. Updating of schedules was almost automated now thanks to advancements in computer vision and data mining methods. Aggregation of the production data into historic cost data, payment applications, and feedback to the field crews was now easy to do, all because the level of detail and organization of the digital production information matched the actual work much more closely than in the past.

He was proud that this system he had implemented was not used to police the field crews, but instead empowered them and made them more productive. Foremen would, e.g., pull all the field deliveries from the various fabrication facilities to the site when needed. They also tracked the on-time performance of the deliveries from the manufacturers so that they knew how much site inventory they should have on hand for a particular manufacturer. Furthermore, dimensional control was now much easier and precise with direct links between coordinates in 3D CAD models and points and positions on site indoors and outdoors. This cut down significantly on installation errors and enabled the crews to carry out much of the quality control as they worked, which eliminated many of the time-consuming, difficult-to-schedule, and imprecise QC tasks that had been the norm not so long ago.

During the virtual site tour, Greg not only reviewed the latest production data such as production rates, schedule performance (including variance from scheduled installation times and durations), inventory on site, workable backlog, supplier performance, and on-time performance of the other contractors and reviewed visual simulations of the next day's work with the site staff, he also listened to concerns and ideas of the workers. One of the workers had an idea for a better design of a field operation with potentially better ergonomics. Greg promised to run a detailed computer simulation over the next two days and share the initial findings from the simulation during the next virtual site visit to determine whether a trial implementation of the new operations design should be planned.

2.5 *Managing organizations to leverage innovations*

A few months ago, the foreman in one of their prefabrication facilities had had an idea for an improvement in the fabrication process. The improvement had required the development of a customized tool and the implementation of adjustments on the shop floor. It also required additional data management steps. Now that the improved process was running reliably in the factory, Greg needed to turn his attention towards educating their information supply chain about the new fabrication capability. The structural engineers they worked with were particularly critical since they were in the best position to influence the structural design so that the new capability would be leveraged to the fullest. Also, it would help the company's detailing and fabrication efforts significantly if the structural engineers would expose additional load data with the structural design objects they passed along in the information supply chain. Such organization and process changes were difficult enough to manage internally; external changes required even more care and attention. Getting ready for the meeting with one of the structural engineers, he had prepared production data and simulations of the old and new process that he hoped would convince the engineer to consider the changes in the design process and information model that would streamline the digital and physical making of structural components. Greg was also prepared to increase the fee for the structural engineer if he would prepare and share the information needed.

In addition to managing the organizational changes necessary for the implementation of the innovative fabrication process, Greg was also planning a pilot project to test the feasibility of a small device that would be added to the field information system each worker had to detect and track near misses, i.e., situations that almost resulted in accidents, which had been an elusive goal so far and could lead to a breakthrough in safety management.

2.6 *Maintaining intelligent systems*

Finally, the last major task of the day for Greg had been the maintenance of the company's intelligent production planning and control system. The fabrication innovation had required changes in the company's product and work breakdown structures, the implementation of new software links between the respective product and process elements in these breakdown structures, the adjustment of the user interfaces(UI) for the detailers, fabrication planners, and shop floor managers, and the collection of new performance data. After several months these adjustments and the data were available, and it was time to go live with the information system that supported the new process. Greg did the final review of the UI, work and information flow, and data with the affected stakeholders and gave the OK for the final steps needed to go live. He also asked one of his assistants to prepare the educational materials needed to train the stakeholders in the use of the new method.

3 SO WHAT?

As Greg's car pulled up to the Thai restaurant it had found, Greg noticed the college classmate he hadn't seen in a while that the car had found as a willing dinner companion. He got out of the car and waved to her. He couldn't wait to tell her about all the great performance improvements his company had identified, piloted, and rolled out across their own and their project organizations since they had last spoken to each other. Now Greg was even more excited about dinner, since Stephanie worked for a large developer, owner, and operator of R&D facilities. Waiting for Stephanie he noticed the packed parking lot of the restaurant. They must have good food, he thought. He also noticed a sign that offered a 10% discount for patrons not requiring a parking space. With denser urban developments space was at a premium everywhere. He was glad that he had already made the switch to the autonomous public cars that had become available on a commercial basis last year. As he was waiting for Stephanie, the car he had used drove off to pick up another passenger. He started to wonder whether the small parking structure coupled with a well-organized and customized public transport option wouldn't be the better option for the healthcare facility he had worked on earlier in the day.

As he and Stephanie settled at the bar in the bustling Thai restaurant to wait for two other colleagues, he explained to her that they had just completed construction on three different $250M projects (a museum, a mixed use development, and a light industry facility) in 6 months each. While doing so, their firm's ideas and practices and early and ongoing collaboration with the rest of the team contributed an 8% reduction in life cycle costs for these facilities and a 6.5% reduction in CO_2 emissions over similar facilities built in the last 10 years. He knew these figures because his firm not only fabricated and assembled part of the building; it also coordinated the virtual and physical making processes. Several years ago they had formalized and implemented an integrated product-organization-process (or building component, resources/stakeholders, task) modeling approach to support the management and coordination of the virtual and physical project phases with an eye on the overall life cycle performance of the buildings they worked on (Figure 1). This approach provided a digital roadmap and documentation for the project at its many levels of detail and the "hooks" to the many company-specific data sets the various stakeholders had and needed to use for their work. Hence, he could plan, track, and show how the scope and schedule and the project impact (first cost, life cycle cost, value to the building user, etc.) evolved over time through the ideas, tasks, and collaboration of the various project team members. In addition to delivering the completed building his company now also handed over a detailed, accurate as-built building information model that provided the basis for the operation of buildings, including facility management, repurposing of a building, reconstruction, etc. In some cases, they had even continued their involvement into the operations phase. In other cases, their well-established work methods and clear communication tools had enabled the company to hire crews with less experience made up of newly arrived immigrants that had been displaced in their home countries due to the rise in productivity in agriculture. He felt that the construction industry in general and his company in particular served society well also in this way.

These performance improvements and his company's expanded service offerings and more competitive market position were enabled by research that provides the theoretical foundation for the virtual design and construction methods that formed the backbone of generating and evaluating ideas and design options through integrated engineering of a project's product, organization, and processes across levels of detail, project phases, and disciplines. Before, it was difficult to understand and make transparent the functional requirements of the main project stakeholders, in particular the future building users, to adjust these requirements as the project evolved, and to evaluate the design options against these requirements. Now, he could explain the project decisions, and the design process engaged the project stakeholders much more actively. The better computational methods with the better organized project information and the more engaged stakeholders led to much shorter latency in responding to questions and making decisions, which increased the entire project velocity and productivity and minimized wasted human and technical resources.

Getting here had required significant attention to the work processes of the company and its partners on projects, the information systems that support these processes, and the formal knowledge basis that enables the rapid and cost-effective construction phase. It also required creating an organization that was not only geared towards providing maximum customer value – to use an overused phrase from the early part of the century – but also to learning from project to project and with a mindset for innovation. Innovations could come from anywhere on the planet; in fact the safety device he was about to pilot had been put together by an inventor in Slovenia. He felt confident that his company was well-equipped to compete in this world of high customer expectations and constant innovation, since it had a well-organized set of processes and tools that made it relatively easy to assess the opportunity presented by an innovative material or method. It also enabled the company to maximize the impact of the expertise and creativity of its engineers and managers on its projects. This had been a huge factor in attracting and retaining top level employees, who saw working at this firm as a way to build on their knowledge of materials, design, fabrication, and assembly methods, and tools for coordination and communication.

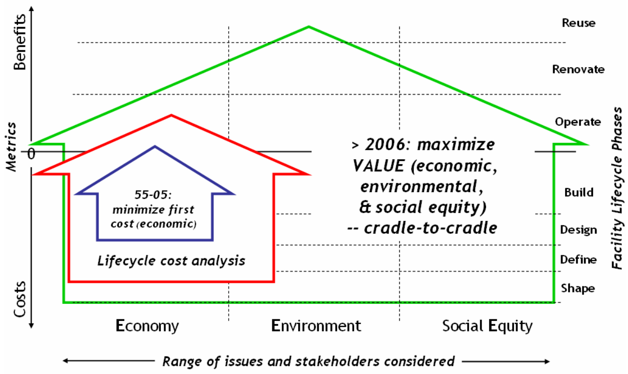

Figure 1. Proposed focus for the work of construction engineers and managers in the future to minimize the cost and maximize the value of facilities over all life cycle phases.

4 CLOSING THOUGHTS

Professionals today already do almost all the work described in the scenarios above; however, in most cases without the support of formal, computer-based models, without explicit and public metrics, and without a schedule that orchestrates stakeholders, decisions, and information flows as best as possible so that appropriate topics and decisions are addressed at the appropriate level of detail and with the right level of effort over the course of a project. The scenarios assume the availability of pervasive computing resources and information devices and an infrastructure that connects people and their devices on demand to available information and computing systems. The methods Greg uses to carry out his work for the day already exist in most parts in a few innovative companies on pilot projects or in research laboratories. Hence, I worry that my descriptions of how Greg will work are too conservative. Nevertheless, the definition, development, testing, and widespread implementation of the suggested work methods is perfectly feasible – and I believe highly desirable and necessary – but will require significant attention from executives and project managers and engineers. It will also require significant research to develop the foundation for the representations and mechanisms that will enable project participants to build appropriate models of a facility's components and systems and the organization and processes that conceive, create, and operate facilities quickly and with enough accuracy to guide project decisions and direction.

Current attention to lean production methods combined with virtual design and construction tools is leading to more reliable workflows and less costly project execution (in terms of initial costs, time, life cycle cost, waste, environmental impact, etc.). I believe that this is a great improvement and of enormous value to the construction industry and to society. This in itself is, of course, already a wonderful contribution of computer-integrated construction. However, just working in predictable ways and reliably executing projects does not fully excite me on a human level, even as good as it will be for the bottom line of companies and professionals. Therefore, I suggest that a truly exciting set of tools and processes should not only lead to reliable and predictable workflows, but should also enable and benefit from the ingenuity, spontaneity, and creativity of its users, i.e., the designers, engineers, and managers who shape the built environment we all depend on through their work and decisions every day.

ACKNOWLEDGMENTS

While I have to assume the responsibility for the scenarios that are too shortsighted or too utopian and for omissions of important trends this paper was inspired by the innovative and thoughtful work of many of my colleagues at Stanford and elsewhere. In no particular order and at the risk of omitting many others whose work has been equally inspiring, they include the following people (even though incomplete, these acknowledgments also serve in lieu of a formal list of references, which would be very long):

- John Kunz at CIFE for opening my eyes to model-based design and construction methods and for his pioneering work in integrated concurrent engineering and the role of process metrics.
- John Haymaker at Stanford for his insights, vision, and work on multi-disciplinary, parametric design processes, and his belief and work in elucidating the goals of stakeholders, prioritizing them, making them transparent to all project participants, and relating them to proposed design solutions.
- Ray Levitt for adding the organizational perspective in a formal way to the traditional concurrent engineering perspectives on product and process.
- Bob Tatum for showing me the opportunities for prefabrication, modularization, and attention to constructability.
- Paul Teicholz for his persistence in pursuing his vision of computer-integrated and data-driven engineering and construction.
- Jen Tobias, an undergraduate student at Stanford, and her collaborators at the CRC for Construction Innovation in Australia for the vision and work on model-based life cycle assessment methods.
- Sarah Billington at Stanford University for highlighting the opportunity to design the structural (and other) building materials for a specific purpose in their particular context and use on a project.
- Mike Lepech from the University of Michigan for showing how the performance of a material affects the performance of a structure, which in turn is a major determinant of a facility's life cycle costs and impact.
- Greg Howell for highlighting the importance of making and managing commitments to achieve reliable workflow.
- Sebastian Thrun in Computer Science at Stanford for his vision of the role of robotic devices to enhance our lives.

- Todd Zabelle at SPS, Jim Glymph (then at Frank O. Gehry & Associates), and Reijo Hanninen at Granlund for believing in and acting on virtual design and construction before other practitioners did.
- David Hudgens at Accu-Crete for showing me the value of a motivated and well-informed work force.
- Reijo Kangas and Ari Ahonen at Tekes for believing in and supporting ideas well before they became mainstream.
- Pierre Bierre from BuildExact for connecting the real world with the virtual world.
- Jennifer Whyte for advancing the understanding of the role of visualizations to support the work of engineers.
- Ari Pennanen from Haahtela for developing a method that allows project teams to define customer value explicitly and in measurable terms and link it to design options for a facility.
- Angelo Pozzi for his leadership in connecting academia and industry and for his holistic thinking.
- Steve Fenves for pointing out the challenge to formalize methods that work across levels of detail.
- Bill McDonough for bringing cradle-to-cradle thinking to this world.
- Visionary practitioners like Dean Reed and Eric Lamb at DPR, Bob Simmons at ConXtech, Greg Knutson and Derek Cunz at Mortenson, Frank Neuberg at Max Boegl, Dirk Schaper at Hochtief, Jan Reinhardt at Turner, Wolfgang Wagener and Rick Huijbregts at Cisco, Mike Williams and Doug Eberhard at PB, Jim Bedrick and Andy Ball at Webcor, Charles Matta and Calvin Kam at GSA, Ben Schwegler and many others at Walt Disney Imagineering, Peter Beck and Stewart Carroll at Beck, Charlie Kuffner at Swinerton, Wallace Kroeker at Smartech, Zuhair Haddad at CCC, Jon Pittman and Phil Bernstein at Autodesk, Buddy Cleveland at Bentley, Joel Koppelman at Primavera, John McQuary and Randy Fix at Fluor, Mike Alianza and Dan Hodges at Intel, David Hovy at Optima, Jim Becker at Skanska, and Carrie Byles at SOM; their sponsorship and support in so many ways makes work as a construction academic fun and rewarding.
- Finally the students at CIFE; without their imagination and dedication none of the work that provided the foundation for this paper would have happened.