

DELIVERING PROJECTS IN A DIGITAL WORLD

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ABSTRACT

A 2004 National Institute of Science and Technology study estimated that the value wasted in developing traditional analog construction documents with non-interoperable information is 40% to 60% of all design cost, or almost \$16 billion per year in the US alone. So, if design processes in A&E firms are digital, and modern constructors have adopted digital modeling as an integral component of their construction management, why are projects still delivered from design to construction using traditional analog information? The purpose of this paper is to identify some of the professional and organizational barriers to implementation of Digital Project Delivery. Digital Project Delivery is, for the focus of this paper, defined as the legal transfer of all project information necessary to construct a project across the design/construction interface with a minimum of analog documents as the primary deliverable. This paper consists of first-hand observations of professional engineers who have practiced on projects where the delivery was digital, primarily design-build transportation projects where the constructor and designer are tightly coupled. A limitation is that these observations were not the result of controlled study, nor are they a cross section of the entire built environment. However, these observations are consistent enough to suggest that Digital Project Delivery would result in a reduction of the cost of producing and communicating non-interoperable information, an improvement of project quality through reduced errors and omissions, and improved morale due to higher reliability and usability of project information, all key components of Lean Construction.

KEYWORDS

Digital, Delivery, Information, BIM, CIM, VDC

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INTRODUCTION

This paper focuses on examples of digital delivery of capital projects from design to construction that the authors, experienced professional engineers specializing in the practice area of transportation project delivery, have personally observed. The objective of this paper is that by providing an “inside the compound perspective” of emerging digital project delivery processes, as well as their associated challenges, future research will be encouraged to focus more on the daily processes that actually deliver projects in a digital environment, in contrast to the more mainstream approach of experimentation with the latest technologies or mass surveys to agencies that build capital projects.

The authors of this paper feel, in general, that most existing research has not gone deep enough into the “mud” of innovative project delivery to authentically communicate the naturally expected chaos, confusion, and emotional resistance they have observed on these example projects, as well as other projects on which they have practiced. There is certainly no shortage of research involving Building Information Modeling (BIM) and Lean Construction. Sacks et al. (2009) discussed synergies between BIM and Lean. Tillman et al. (2015) discussed the role of BIM and Lean in the design and production of engineered-to-order items. Merschbrock and Munkvold (2012) conducted a literature review on building information modelling research and concluded that organizational areas are ripe for research. Mandojano et al. (2015) discussed the role of virtual design and construction in the context of the 8 waste types. Gerber et al. (2010) discussed advances from practice in BIM and Lean Construction. Hamdi and Leite (2012) discussed the maturity of interactions between BIM and Lean in the construction phase. Gerber et al. (2010) discussed how BIM and Lean could be used to support the entire lifecycle of a building. There are dozens (perhaps even hundreds) of additional papers, thesis, dissertations, and even books available on this subject, far too many to address within this text. There are also a significant number of papers within the Transportation Research Board on the emerging roles of BIM, Virtual Design and Construction (VDC), Automated Machine Guidance (AMG), Civil Integrated Management (CIM) and 2D/3D combined with other attributes such as time, money, risk, safety, etc. (xD) in the design and construction of infrastructure projects.

This massive amount of research, some going as far back as twenty years, shows an intensification of activity about the potential of BIM (and other similar technologies) to support Lean goals. However, the authors feel that much of this existing research is heavily focused on the use of BIM within the confines of either the design profession or the construction industry, while research on the fundamental nature of the digital information that must cross the legal (and litigious) boundary from design to construction (whether it’s in the form of BIM, CIM, VDC, xD, or any of the other cacophony of acronyms used by the AEC sector) has been generally overlooked. This boundary is most distinct in public infrastructure work delivered through the design/bid/build model. The author’s positive experiences with the reduction of this boundary, or at least of the boundary’s negative effects in the context of improving flow, in design-build delivery suggest an untapped opportunity for improvement on mainstream projects.

A BRIEF HISTORY OF PROJECT DELIVERY INFORMATION PRACTICES

Projects in the built environment, because of their spatial nature, are delivered by highly visual documents. These documents are generically known as “technical drawings”. The limitation of technical drawings is not just that they are a 2D image in a 3D world, but that they are analog information in a world that is increasingly digital. In the context of this paper, analog information is anything that must be interpreted by a human being before implementation on a construction project, as opposed to digital information which is capable of being moved directly from one computer to another, even if the information requires approval by an intervening person. The use of these two terms in describing construction information is analogous to calling a slide rule an analog computer and a calculator a digital computer. Examples of analog information, whether physical or electronic, would be ink on mylar, laser toner on paper, and raster PDF’s. Examples of digital information would be ASCII files, .dgn, .dwg, .dxf, .rvt, etc. It is interesting to note that digital information can exist in physical media as well as electronic. Paper tapes and punch cards predate magnetic tape and hard drives, yet still were (and hopefully are) able to effectively communicate digital information.

Our current practice methods in the creation, formatting, and reproduction of technical drawings, also known as “plans”, extends back into the mid 1800’s. In 1861 Alphonse Louis Poitevin, a French chemist, discovered a chemical that turns blue when exposed to light. This discovery led to the ability to produce multiple white on blue drawings, or “blueprints”, from a single translucent drawing. Advancing technology eventually led to blue on white, then to black on white, then to xerographic, and most recently to drawing in the digital world of a computer with output send to pen plotters, laser printers, and even electronic PDF sheets. However, our project delivery practice methods are still rooted in the transfer of what we might call “rectangular boundaries of analog information,” or drawings.

In the late 1990’s to early 2000’s, advanced contractors began reverse-engineering these analog drawings into digital models suited for construction, specifically for layout using “rovers” (survey instruments where the computer containing the digital model was attached to the vertical rod instead of a total station on a tripod) or AMG where Global Positioning System (GPS) or laser positioning systems are mounted on bulldozers, scrapers, or graders and combined with a computer in the cab which has the digital model. The reverse-engineering of the analog drawings was in spite of the fact that these documents were almost always created from a digital 2D or 3D model in the first place.

The introduction of design-build in the delivery of transportation projects allowed the design engineer and the constructor to be tightly coupled under the same contracting entity. This tight coupling encouraged greater flexibility in the information flow from design to construction. Design-build teams began experimenting with the transfer of the digital design information directly to construction for use in rovers and AMG equipment, with the analog documents being produced in parallel for the owners and other traditional stakeholders based on contract requirements for traditional deliverables.

A BUSINESS CASE FOR DIGITAL PROJECT DELIVERY

A 2004 report issued by the National Institute for Standards and Technology (NIST) titled “Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry” estimated that 40-60% of the time and cost of all engineering in project delivery is consumed creating, communicating, and recovering non-interoperable information. This report estimated that cost in the US at around \$15 billion annually. The persistence of non-interoperable information is a legacy from the analog technologies we used in the past to deliver projects. Granted, those technologies, i.e. reproducible prints, optical survey instruments, drafting tools, etc., were the best we had at the time. However, these legacy practices consume resources without adding value. *They have ceased to add value because the technology limitations that created them no longer exist.* Capital projects can, and have, been delivered from design to construction with pure digital data while remaining fully compliant with the practice regulations issued by State boards of engineering.

In 2014, the Construction Institute (CI) of the American Society of Civil Engineers (ASCE) created a new committee for Digital Project Delivery, whose purpose is to “facilitate the transition of civil engineering practice from delivering projects in the traditional analog form of drafted plans and narrative specifications to the emerging capability of delivering projects using digital data contained in advanced models, whether 2D or 3D, and machine readable technical requirements.” The Federal Highway Administration (FHWA) has also started an initiative called CIM which they define as “the technology-enabled collection, organization, managed accessibility, and the use of accurate data and information throughout the life cycle of a transportation asset.”

FIRST-HAND OBSERVATIONS BY CONTRIBUTING AUTHORS

The following of examples of digital project delivery were either observed or experienced first hand by the authors:

Communication of Digital Design to Construction Year: 2005

Engineering firm “X” prepared plans and specifications for owner “Y” on a transportation project that bid at approximately \$100 million. After the analog plans were delivered, both PDF and laser-printed mylar, the owner also requested a CD of the design firm’s source 2D master files (Bentley Microstation .dgn), which contained all the design information that referenced into the plan sheets. After the project was bid, the owner gave a copy of this CD to the contractor without warranty, i.e. “for information only.”

The contractor was digitally-capable, and brought these files into their own digital construction environment (Trimble Terramodel) for analysis. As a result of comparing the digital master files against the legal plans sheet for all of the storm drainage on the project (several hundred sheets covering about \$15 million in construction) the contractor noticed that over half of the callouts were in error (callouts provide the Station and Offsets of elements that require construction, a form of curvilinear coordinate system

routinely used in transportation construction) and notified the Principal of the engineering firm in confidence without formally going through the owner.

After an internal investigation within the engineering firm determined that the source of the problem was incorrect referencing of the master files into sheets causing the incorrect callouts, the principal of the firm made a personal agreement with the contractor warranting the accuracy and reliability of the master files, allowing the contractor to proceed with construction at minimal risk. The alternative would have been weeks of costly delay claims until all of the incorrect sheets were revised, printed, and channelled back through the owner's document management process for official issue to the contractor. The contractor used the engineer-warranted digital files as input into their own digitally-driven survey and construction process, and only printed out analog sheets as needed for any subcontractors who did not have digital capability.

In the meantime, the engineering firm created new sheets with the master files correctly referenced in, created correct callouts (which were double checked this time), and issued formal revisions to the owner. By the time the revised sheets made their way through the owner's system and were issued to the contractor, the correct storm drainage system had already been laid out and actual construction was well underway.

The apparent lean principles at play in this incident appear to be: (1) defects in the original plans sheets, (2) waiting that would have occurred if the contractor was forced to wait for revised sheets, and (3) non-value added processing in the form of callouts on plans sheets that were not actually needed by the contractor, but required by the owner's legacy plans preparation standards. Allowing the contractor to build directly from the digital data is an example of efficient flow, because the information went directly from the design engineer's computer to the construction surveyor's computer.

Digital Construction Quality Assurance Year: 2008

Engineering firm "M" was a sub-consultant teaming partner to a design build Joint Venture team of Designer 'J' and construction firm 'K' contracted to deliver a project valued at \$200 million. Owner "S" issued a Request for Proposals requiring the design build team to retain a quality assurance engineering firm independent of the engineering firm designing the project.

Engineering firm 'M' was brought into the proposal team as the 'Independent Quality Firm' (IQF). As the IQF, 'M' was to review the entire design, both analog plans and digital models, to verify that the design conformed to all contract requirements for design. Following this review, the IQF would be the final authority to give the traditional analog construction documents the status of 'Released for Construction' – allowing the contractor to build the facility. The IQF was also tasked with all of the inspection, sampling, and testing of the construction work to professionally verify that contract requirements for construction were being met.

From previous experience on other projects delivered through the design build model, firm 'M' knew that the task of verifying that all work conforms to contract requirements would be very labor intensive using traditional analog practices. To address this challenge, and quite frankly to improve their own profitability on a fixed price contract, firm 'M' developed a geospatial database model that was configured to allow firm 'M's

engineers to identify and upload all the individual requirements listed in the contract documents. This digital approach to design review and verification provided a positive confirmation of requirement fulfilment as opposed to the traditional analog approach of “slogging” through thousands of plan sheets looking for errors or omissions – a punitive type of review. Reviewing and verifying design through a digital approach allowed for efficiencies in IQF design review staff time as well as decreasing the review schedule time.

To fulfill the IQF task of professionally verifying the quality of the constructed, firm ‘M’ also utilized the relational database of contract requirements. As tools to collect field data, firm ‘M’ procured a number of handheld high-accuracy GPS data collectors. These tools have customizable software that facilitated the collection of specific types of data complete with engineering-grade geospatial location. Field IQF staff used these tools throughout the construction day to record all field data against the design and specifications. Normally the data was measured by other instruments (such as nuclear density gauges, slump cones, air content meters, soil moisture meters, measuring tapes, smart levels, thermometers, reflectometers, turbidity meters, etc) and manually entered into the data collector to be paired with the calculated XYZ location and time of the measurement. This digital data collected at the construction site was then uploaded at the end of each day back into the main database to allow verification reports to be generated and published into the project record.

By using geospatially-enabled digital data collectors, coupled with the database of requirements, the IQF construction inspection and testing staff were able to verify significantly more construction work with fewer manhours, reducing the number of field inspection staff that would be typically assigned to a project of this size. Side benefits of this digital/requirements-management approach to construction quality management included a reduction in both the number of disputes as well as the time to review the evidence supporting monthly payment requests for work completed. Federal regulations require professional engineers to base payment approvals on a review of all the quality assurance data for completed work to verify compliance, a very time-consuming effort in the analog world. Similarly, project closeout efforts were reduced because the data used for acceptance were contained within one database that included both requirements verified and material test results.

The apparent lean principles at play here would seem to be: (1) transportation in that the field staff did not need to carry large documents in order to have all of the information needed to effectively perform quality assurance, (2) motion in that much of the data (date, time, location, user) was collected automatically by the handheld data collectors eliminating the need to constantly fill out forms, (3) waiting in that the collected data could be compared with the master design model at the end of each day, with automatic determination of any measurements not conforming to the contract requirements. If the inspectors had been equipped with the more expensive survey-grade equipment (+/- 1cm real time accuracy) instead of high accuracy mapping-grade equipment (+/- 10 cm real time accuracy and +/- 2cm post processed accuracy) the wait time for verification would have been zero.

Digital Design Development and Delivery to Construction Year: 2010

Project “X” was awarded as a \$1 billion design build highway contract. Many of the project elements were designed through the use of digital files prior to construction with emphasis placed on avoiding conflicts with roadway/structural elements and utilities. The digital files assisted in developing a design that provided more confidence in avoiding conflicts in the field and led to discovering and analyzing how many of the design elements interacted. Care was taken as not all project elements were modelled. Elements such as traffic lightings and posts and overhead signing was not digitally developed as the scope of work and schedule restricted the level of detail for this project.

The digital data was brought together and used as part of a weekly design meeting between the design build team. The design consultant would post the current version of the 3D digital model to a central server. The review of the model as a group drove discussions on means and methods, phasing, and locations. Through this process, the design build team realized material and schedule savings or was able to value engineer alternative designs.

Once the digital design model was complete, the contractor would use it’s own software to simulate grading or construction of project elements virtually. This served as a “sanity review” of the data and confirmed that there were no gaps in the digital model and that the necessary data had been provided to the contractor by the design consultant. Upon official receipt of the model by the contractor, the contractor directly delivered the digital data to GPS/Laser fitted construction machinery or digital survey equipment to construct project elements AMG. The owner still required a hard copy plans submittal and approval of the “analog” design, and there were no digital delivery requirements by the owner. The contractor managers chose to use digital delivery as they believed this approach significantly reduced risk and accelerated construction for this project.

The process of developing and delivering the digital files has its challenges along the way. At project initiation the project manager for the contracting team believed every element of the project would be developed in a 3D digital environment, including the smallest details. Given the scope of work for the design consultant and quick schedule associated with winning the project this was not possible. Once the project was awarded, key elements were developed at finer granularity as needed.

The largest challenge encountered in delivering digital design to construction was the compressed schedule and determining the priority of delivery for segments of the project. The project was broken into three key areas and the design team had a lead digital delivery person for each section and a fourth, lead digital delivery coordinator. As the project evolved the digital delivery team mentored others to ease the burden of workload on the digital delivery team. There were a few segment leads who were originally resistant to the development of design in a fully digital environment, but they eventually came to rely on the ability of the team to coordinate using the digital model as a means for coordination and delivery.

Another challenge was that one of the key design subconsultants (subs) was not experienced with developing a digital design model in 3D, even though they were using the same software platform as the lead design firm. The team discovered that the sub was

not updating the master digital design model as the design evolved, but was keeping all of their information in the traditional legacy design environment used to create 2D analog plans. This created a situation that initially prevented digital file coordination. After multiple delays and coordination issues, the lead design firm was forced to take over and manage the digital development of these files as the project team saw the necessity and advantage the digital delivery process provided. The sub coordinated the design with the lead design firm after this discovery, and while the process was streamlined still provided challenges with every day coordination and development of the digital model

The apparent lean principles that would seem to be in play here are: (1) overproduction in that project elements were not modelled in fine granularity until that level of development was needed. Some elements were not modelled at all if it was determined that analog information delivery was more efficient, and (2) waiting in that different project teams did not need to spend time preparing traditional documents to communicate their design to the other parts of the team.

Digital Design Quality Assurance Year: 2011

Engineering firm “W” was the design firm for a \$1 billion design-build transportation project under contractor “Z”. While the contractor had advanced digital capability, the owner still required the submission of analog construction plans, both PDF and paper, as well as the submission of paper “check prints,” or quality control prints, showing where each plan sheet had been reviewed; any errors discovered were marked in red, and all correct information highlighted in yellow. Because of the intent within the design-build team to legally transfer any complete digital design information directly to the construction surveyor, after being digitally signed according to the State Engineering Practice Act, the design quality control was implemented with a corresponding digital process.

As the design was being developed, the design quality control engineer referenced all the relevant design files and models into a separate review environment. The semi-live design was reviewed against all contract requirements and design standards and notations from these review, for both correct and incorrect features, were placed in a review file that had the same coordinate system as the 2D design files. In cases where the design review required generation of static 3D models, such as verifying that certain tie-in points had matching elevations, all notations were placed in a 3D file at the XYZ coordinate of the design feature that had been reviewed.

These review files were then referenced back into the live files being continuously developed by the design engineers where any errors or conflicts were corrected. Once the digital design files were approved and sent to the contractor, analog plans for the owner’s consumption were printed from both the current set of design files as well as the pre-review file snapshots. The review files were projected on a wall in a conference room where the design engineers assisted the quality control engineer in transcribing the digital review into red and yellow marks on the printed plan sheets. This transcription process was surprisingly fast. The final paper copy and the red and yellow “Check Prints” satisfied the owner’s document control requirements, even though the project was being constructed using digital data and not the plans.

The apparent lean principles at play in this incident appear to represent: (1) overprocessing in the sense that physical documents were being created only to satisfy a legacy contract requirement; (2) motion in the sense that additional work was required to create the Check Prints with no added value, and (3) batch size in the sense that the review was conducted in small increments as each part of the design was complete, rather than waiting for a large set of review prints at 30%, 60%, and 90%. The near-real-time review by the design quality control engineer offers an example of flow in the sense that the design could be reviewed as soon as it was ready without the need for additional preparation or printing. The results of the reviews were immediately available to any design engineer that needed it. The audit trail of the reviews allowed for anyone to see the progress of the design, as well as any design changes or correction, at any time period or any physical location of the proposed construction.

DISCUSSION

These examples provided by professional engineers working on projects with components of digital project delivery illustrate some of the challenges faced by practitioners. These first-hand observations are by their very nature non-random and not necessarily representative of mainstream project delivery. However, they do illustrate some of the ways that digital project delivery is possible, and some of the roadblocks faced by innovators in the way of legacy processes, policies, or contract requirements. *One of the key themes in most of these innovations is the tendency for individual practitioners to “work around” apparent flaws in the contract documents or organizational processes.*

Although technology has enabled improved practices, the legacy language in contracts may actually discourage their use, or still require an obsolete practice resulting in double work. If digital project delivery is to become mainstream in the future, the professionals in charge of project delivery will need to modernize contract documents and organizational procedures and requirements to support, or even encourage, these new capabilities. This implies the need for active involvement of lawyers, insurers, contract writers, and even politicians, not just engineers, architects, and contractors.

CONCLUSIONS OF AUTHORS

The authors of this paper hope that these examples help to communicate the potential of delivering projects digitally without the burden of analog documents and legacy contract requirements. Our intent is that these examples encourage the growth of field research by academics who are embedded on innovative projects at the lowest levels, whose primary responsibility is to identify the fundamental theories involved in the deployment of these new digital processes, as opposed to the ad-hoc sharing of first-hand experiences by licensed professionals within the confines of gatherings of practitioners.

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