Construction Drawings: A Cost/Benefit Case Study of Weather and Tear Resistant Drawings

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Construction drawings are vital tools that contractors need to complete a building project. Drawings are used constantly on the construction site in all types of weather. Often, these drawings become wet, torn, faded and generally damaged beyond use. If this damage is significant, errors in plan reading are possible. Many contractors also report purchasing multiple sets of drawings for the same project. These additional sets of drawings add costs to the project. Technology is now available to extend the life of drawings which uses tear resistant paper and a water resistant printing method. Of the potential cost savings on the job, the direct reprinting costs are the easiest to quantify. This study seeks to quantify the cost difference currently available on the market for several specific projects. First, the weather and tear resistant drawings are discussed. Second, a review of the use of different types of drawings on the jobsite was made, and key areas that would benefit from the use of more durable drawings are identified. The study analyzed the drawings on several types of projects to evaluate the cost benefit relationships. Results indicate that the technology may be marginally beneficial for smaller projects. For larger projects, the benefit of durable drawings appears more significant when compared to the overall costs of the project.

Key Words: Construction drawings, Tear resistant drawings, Water resistant drawings

Introduction

Construction drawings are necessary for every project and have multiple users as well as multiple uses. Previously, all drawings, regardless of the use and user, were of the same or similar material and were printed using essentially the same process. There are now some options in drawings, which provide greater durability for the end-user. One technique is the lamination of drawings, and the second is the use of tear resistant paper and water resistant printing methods. Both of these methods cost more to produce than traditional construction drawings. However, more durable drawings are valuable for certain users and applications. The three main user groups are the construction management team, the owner team, and the subcontractor team. Within each team, there are multiple users. Each user often has different requirements for which specific drawings are required, the length of time the plans are used, and the conditions under which they are used. The following study examined each of the user groups, the different drawings used by each group, how the drawings were used, and when more durable drawings should be considered. Three case studies were then employed to evaluate the use, the cost, and the potential benefit for three different types and sizes of projects.

The Drawings

The need for drawings that are more durable has been expressed by industry professionals (Smith, Farrow & Walker, 2007). The first response to the need was lamination of the individual

drawing sheets. The process does a great job in protecting the sheets, but can become awkward to use in some applications. Lamination adds weight to the sheets and makes the sheets more difficult to bend or flex. When a larger set of plans are used, the laminated drawings can become bulky and difficult to manage. This may not be a problem for electricians and interior carpenters who have tables that the plans can rest on all day. However, it could be a significant issue for other applications, such as form work erection, structural steel erection, placement of reinforcing, site excavation, and other trades that are out in the open and moving around.

The second product has recently been developed, which combines tear-resistant synthetic paper (Seth, 1988), similar to the paper used in house-wrap (DuPont, 2007), with water resistant printing methods. This combination of readily available technologies provides a set of drawings which is water and tear resistant, and as lightweight and flexible as bond paper. The cost of the durable drawings is significantly higher than plans on bond paper. This increase in cost is due to the cost of the paper, the cost of the ink, the equipment, and printing methods. The equipment used for the printing is similar to equipment used on exterior signs in order to use the water resistant ink. The labor to print is significantly higher than bond printing. Bond prints two-feet by three-feet can be printed at 22 sheets per minute, while the durable prints can only be printed at rate of 1.1 sheets per minute. The resulting cost for the durable drawings is $4 per two-foot by three-foot sheet, as compared to $1.08 for standard bond paper and standard ink (Smith, Farrow & Walker, 2007).

The value of the durable drawings has been investigated and field tested. The investigation involved surveys with construction industry professionals. The results of the survey revealed that for certain trades, multiple sets of drawings were necessary because plans were damaged through use and weather. A light rain or dropping a drawing in water would destroy the drawing and it would need to be replaced. Workers fold and refold drawings as they are working on a project, and standard use will lead to unreadable drawings. Depending on the size of the job and the weather conditions, plans needed to be reprinted one to three times, so it could take four sets of prints to complete a job. The reinforcing steel installer on one project said that seven sets were delivered when the steel arrived. Such a scenario could justify the price difference on the cost of printing the drawings alone (Smith, Farrow & Walker, 2007).

The field test was conducted by giving a durable set of rebar erection drawings to ironworkers on a cast-in-place concrete structure. Prior to receiving the durable drawings, two sets of drawings had been in use and become too damaged to proceed. The damage was expected, as seven sets of re-bar drawings were provided when the re-bar was delivered. The workers commented that typical field drawings were often punctured by the wire used to tie the rebar together. No tears or punctures were present in the durable rebar drawings after six weeks of use on the construction site. The workers also shared that if traditional drawings became wet, they would have to hang the drawings to dry for one and a half days. After that time-consuming process, some of lines had blurred and faded. In one instance, the improved field drawings were accidentally left in a puddle for approximately thirty minutes, and the trade workers were able to pick them up, shake the drawings and continue work without any delays. Thus, “puncture resistance” and “water resistance” were the most impressive traits of the drawings to the workers. With the improved sample drawings, the iron workers were able to complete all sections of work required without reprinting. It was noted that due to the fabric-like properties of the durable paper, the drawings

had a slight reddish-orange discoloration from the clay on the jobsite. This slight discoloration did not affect the readability of the drawings, and the waterproof ink was in the same condition as the day it was printed (Smith, Farrow & Walker, 2007).

Since the cost of the durable drawings is significantly higher than drawings on standard bond paper, the additional cost may not be prudent in many situations. The most cost effective way to get the benefit of the durable drawings, while holding the cost down, would be to use a combination of the standard drawings and the durable drawings. The bundling of the two different types could become effective, based on the user needs. The following discussion looks at the different users of the drawings, how the drawings are used, and which drawings would benefit from the more durable product.

The Users

The first user in a project is the owner. The owner receives drawings which are the architectural team's representation of the project. The owner receives one or more sets at the beginning of the project, with additional sets available to interior designers, office furniture suppliers, and any owner supplied subcontractor on the project. These sets are rarely outside a conditioned office environment and would likely not benefit from using durable drawings. At the end of the project, the owner will receive one or more sets of "as-built" drawings. These drawings are used for maintenance and renovation. Over time the drawings may have notes on the location of equipment, information on new equipment, notes on changes in the building, and other information relevant to the maintenance and changes in the project. The notations on the drawings become valuable, so it is important to maintain the original set of drawings. The ability of this "as-built" set to withstand multiple maintenance and renovation issues and maintain the readability of notes added to the drawings would be enhanced by the use of the durable drawings. Thus, durable drawings could be specified in the construction documents as a protection for the owner. The National Park Service is responsible for the lifetime administration and maintenance of its buildings. As a result, Director's Order 10A says, "Accordingly, the materials used for all drawings must have a minimum life expectancy of 100 years (Murphy, 2003)."

The construction manager or general contractor (CM/GC) will receive several sets of drawings at the beginning of the project. One or more sets will be retained by the government body issuing the permits for construction. The CM/GC will retain one set of drawings at the home office and one set of stamped (stamped by the permitting entity) drawings will be required to remain on the jobsite, usually in the job trailer. All but the job trailer drawings remain inside conditioned space and would not benefit from the use of durable drawings, but the job trailer drawings are the official set of drawings on the jobsite. All changes and notations are made on this set of drawings, and this set of drawings is the basis for the "as-built' drawings. The value of using durable drawing for this set of drawings does not come from the replacement cost, but from the value of documentation on a set of drawings which cannot be easily replaced. Projects with long durations could especially benefit from using durable drawings for the job trailer set. Finally, there is often one set of drawings that goes out on the jobsite on a regular basis as the "plan table

set." The plan table set could benefit from using durable drawings due to its high use and direct exposure to weather conditions.

The subcontractors are the last group that uses drawings on the construction project. In the initial phases of the project almost all subcontractors are working in conditions directly exposed to weather conditions. Site work subcontractors, foundation subcontractors, steel erectors, formwork erectors, and ironworkers all use drawings in all types of weather conditions. These trades are also the most abusive to drawings requiring multiple sets of drawings on every project. All of these types of subcontractors would benefit from using the more durable drawings. Subcontractors that arrive at the jobsite after the building is "dried in" and "conditioned" may have less demand for durable drawings. However, these subcontractors often have multiple comments and notations that are added to drawings to enhance their understanding of the project and the work that is to be completed. Use of durable drawings for these trades may help limit rework and improve productivity.

The Projects

In an effort to quantify the costs and benefits when using durable drawings, three individual projects were used as case studies. Construction projects come in all shapes, sizes, and complexity. Larger projects have more drawings, and drawings will be used for longer periods. Each of the projects examined have different scopes and complexities. The first project selected was a 10,000 square foot, one story fire station. The second was a three-story, 45,000 square foot classroom and office building. The third was a three story, 150,000 square foot student center building on a University campus.

To date, few jobs have used the durable drawings discussed in this paper making a cost/benefit evaluation of the durable drawings difficult from a quantitative approach. The newness of the technology coupled with a lack of clear connection between costs and benefit have limited the implementation to date. As such, a quantitative approach based on actual costs was not possible. This case study was considered reasonable and appropriate since assumptions made were readily inferable from the current state of practice.

The Fire Station

The fire station plan set contained 27 sheets:

- Five civil drawings (C)
- Nine Architectural drawings (A)
- Four structural drawings (S)
- Three plumbing drawings (P)
- One mechanical drawing (M)
- Four electrical drawings (E)

The building had CMU bearing walls, brick veneer exterior, light gage steel trusses, and a "medium" amount of interior finishes. The duration of the project parts were not long enough to need more than two field sets and one office set for most trades using normal bond paper prints.

Only one set of durable prints would have been required for each trade. Table A estimated the types of sets and number of copies required for each drawing user on the fire station.

Table A: *Drawings for the Fire Station*

		# of	# of		# of	Combination	
Plans for:	Pages in Set	Pages	Sets	Standard	Sets	Standard	Durable
Owner	Full sets	27	2	54	2	54	
Owner	As-Built	27	1	27	1	0	27
CM/GC	Permit-Jobsite	27	2	54	2	54	
CM/GC	Home Office	27	1	27	1	27	
CM/GC	Plan table	27	1	27	1	0	27
Survey/ Layout	5 C, 2 A, 2 S	9	3	27	2	9	9
Excavation	5 C	5	3	15	2	5	5
Site work	4C, 2 A	6	3	18	2	6	6
Foundation	2 A, 2 S	4	3	12	2	4	4
Structural	4 S	4	3	12	2	4	4
Plumbing	1 C, 2 A, 3 P	6	3	18	2	6	6
Mechanical	2 A, 1 M	3	3	9	2	3	3
Electrical	2 C, 2, A, 1 M, 4 E	9	4	36	2	9	9
Mason	1 C, 5 A	6	4	24	2	6	6
Interior finish	8 A	8	10	80	8	80	0
Flooring	2 A	2	3	6	2	2	2
Total Sheets				450		269	108
Cost per Sheet				$1.08		$1.08	$4.00
Cost by Type				$486		$291	$432
Total Price				$486			$723

The Three Story Classroom Building

The three story classroom building was a steel frame structure, with CMU back-up and brick and precast exterior. There were about 45,000 square feet in the building. The interior has a "medium" level of finishes.

The plan set contained 119 sheets:

- 43 architectural drawings (A)
- 7 civil drawings (C)
- 16 structural drawings (S)
- 21 mechanical drawings (M)
- 13 plumbing drawings and Fire Protection(P)
- 19 electrical drawings (E)

Table B estimated the types of sets and number of copies required for each drawing user on the classroom building.

Table B: *3 Story Classroom Building*

Plans for:	Pages in Set	# of Pages	# of Sets	Standard	# of Sets	Combination Standard	Combination Durable
Owner	Full sets	119	2	357	3	357	0
Owner	As-Built	119	1	119	1	0	119
CM/GC	Permit-Jobsite	119	2	357	3	357	0
CM/GC	Home Office	119	1	119	1	119	0
CM/GC	Plan table	119	1	119	1	0	119
Survey/ Layout	5 C, 5 A, 3 S	13	4	52	2	13	13
Excavation	5 C	5	3	15	2	5	5
Site work	4C, 2 A	6	3	18	2	6	6
Foundation	2 C, 5A, 3 S	10	6	60	2	10	10
Structural	16 S	16	5	80	2	16	16
Plumbing	1 C, 4 A, 13 P	18	5	90	2	18	18
Mechanical	4 A, 21 M	25	5	125	2	25	25
Electrical	2 C, 4 A, 5 M, 19 E	30	5	150	2	30	30
Mason	1 C, 12 A	13	8	104	2	13	13
Interior finish	35 A	35	14	490	14	490	0
Flooring	5 A	5	3	15	3	15	0
Total Sheets				2270		1464	384
Cost per Sheet				$1.08		$1.08	$4.00
Cost by Type				$2,452		$1,581	$1,536
Total Price				$2,452			$3,117

The Student Center

The student center was a 182, 717 square foot, three story building. The structure of the building was cast-in-place reinforced concrete. The exterior of the building was brick and the interior of the building had medium level finishes. The duration of the project was two years.

The drawings on the project had 334 pages for the building and over 300 pages for the food services. There were also 8 pages of landscaping drawings. Only the building plans were evaluated.

- 10 civil drawings (C)
- 46 structural drawings (S)
- 120 architectural drawings (A)
- 51 mechanical drawings (M)
- 37 plumbing drawings (P)
- 72 electrical drawings (E)

The number of sets used on the project, using standard paper and the durable paper, was higher on this project than the smaller projects due to the duration on the project, the scope of project,

and the number of parties involved. The layout and the foundation had a duration of months instead of days or weeks on the smaller projects. The form work and rebar for the structure of the building also lasted several months. The drawings used for the structural work would actually include shop drawings over the structural drawings, which would elevate the number of sheets required. Plan sets for most of the subcontractors would be divided into smaller sets for each section and floor of the building, but are lumped together on the table. The Permit-Jobsite had three sets instead of two, and one of the sets was durable due to the length of time for the project and the need to keep notations on a master set. The master set on the project had notes on all the changes, which were not a sheet change, but an 8.5x11 sheet showing the change was kept in a separate binder. The number of sets does not change on the interior finishes, as there were numerous trades which needed the drawings, but the drawings would generally hold up through their scope of work.

Table C: *Drawings for the Student Center*

		# of	# of		# of	Combination	
Plans for:	Pages in Set	Pages	Sets	Standard	Sets	Standard	Durable
Owner	Full sets	344	3	1032	3	1032	0
Owner	As-Built	344	1	344	1	0	344
CM/GC	Permit-Jobsite	344	3	1032	3	688	344
CM/GC	Home Office	344	1	344	1	344	0
CM/GC	Plan Table	344	1	344	1	0	344
Survey/ Layout	10 C, 46 S	56	7	392	2	56	56
Excavation	10 C	10	4	40	2	10	10
Site work	5 C, 10 A	15	4	60	2	15	15
Foundation	15 S, 8 A	23	7	161	2	23	23
Structural	46 S	46	6	276	2	46	46
Plumbing	20 A, 37 P	57	5	285	2	57	57
Mechanical	20 A, 51 M	71	5	355	2	71	71
Electrical	20 A, 72 E	92	5	460	2	92	92
Mason	35 A	35	8	280	2	35	35
Interior finish	80 A	80	10	800	10	800	0
Flooring	10 A	10	3	30	3	10	0
Total Sheets				6235		3289	1437
Cost per Sheet				$1.08		$1.08	$4.00
Cost by Type				$6,734		$3,552	$5,748
Total Price				$6,734			$9,300

Results

Table D indicates the cost of standard bond plans for each of the projects as compared to the use of a combination of standard drawings and durable drawings.

Table D: Cost Comparison of Standard Bond and the Combination of Drawings

	Building Cost	Cost of Standard Drawings	Cost of Combination o Drawings	Difference in Cost	% increase in Cost	Increase as a % of Job Cost
Fire station	$1.5 million	$486	$723	$237	49%	0.016%
3-Story Building	$9 million	$2452	$3117	$666	27%	0.007%
Student Center	$54 million	$6734	$9300	$2566	38%	0.005%

One could argue that there are certainly economic consequences of using the bond prints that are not durable over time. Prints that are unreadable, lost hand marks that fade or are washed away with water, torn sheets with missing information all have potential financial penalties that are difficult to quantify. One error made on one job could have tremendous financial consequences.

Analysis and Conclusions

Previous research has indicated that the use of durable drawings on a job site has reduced the number of drawing sets required to construct certain elements of a building project (Smith, Farrow & Walker, 2007). This study focused on the relative costs and benefits of using a combination of traditional bond drawings and the more durable drawings for three specific projects. From a cost perspective, there was definitely a premium to using the more durable drawings. This premium represented a 49% increase in printing for the small job (fire station), a 27% increase in printing for the medium job (classroom structure), and a 38% increase in printing for the large job (student center).

While in the increased costs appeared significant on first observation, they represented a very small portion of the overall project costs. Using typical construction pricing for the types of structures and finishes present in each building, the authors' determined the estimated costs of the firehouse to be $150/sf., classroom building to be $200/sf., and the student center to be $291/sf. For the smaller project, drawing costs are 0.016% of total construction costs. This percentage decreases to 0.005% for the larger project. For this larger job, it only represents a $2,566 increase in drawing cost for a project that is estimated to cost $54 million.

Realizing the cost premium for the larger structure as a benefit later during construction or during the lifetime of the structure would not be difficult to achieve. Using an average labor rate of $30/hour, the savings of 85 hours on this two-year project may justify the costs of the more durable drawings. The lost time due to rain on a rebar placement crew or steel erection crew could more than offset the cost premium.

For small projects such as the fire station, use of the more durable drawings may not be

warranted. Although the cost premium is minor, most sets of drawings required will only be used for a few days. Bond drawings are anticipated to perform satisfactorily in most conditions for a short time. For larger projects, the use of more durable drawings can be more easily justified. The longer time frame required for the job, coupled with the relatively insignificant premium to the overall job costs for upgrading to more durable drawings, is a compelling justification for using the improved drawings.

One barrier to the implementation of the use of more durable drawings is that the drawings are not readily available at most local printing companies. These durable drawings are available online through selected providers. Local printing companies have been reluctant to implement this approach due to the initial costs of equipment and supplies. In addition, local printing companies mainly serve local clients. Often the volume of these local clients would not be sufficient to warrant investment in production of more durable drawings.

The accuracy of the cost-benefit analysis is dependent on how accurately costs and benefits have been estimated. For this study, the costs of the printing options were computed based on two foot by three foot drawings, using the rate of $1.08 per sheet for standard bond and $4.00 per sheet for durable drawings. These costs were hard and tangible. This study has not specifically addressed all aspects which contribute to the financial benefits of using the more durable drawings. Instead, it relies on relatively crude heuristics ('rules of thumb') to estimate the financial benefit of the drawings. The benefits are soft and intangible. Further studies could identify specific financial benefits and compare these directly to the costs.

As the technology improves and efforts are made to improve the process of producing more durable drawings, the authors' anticipate that the cost premium will decrease. It is possible that a price point exists where owners, contractors, and sub-contractors would choose to use the more durable drawings in lieu of all bond prints. Further studies are needed on how to lower the costs of the more durable drawings in an effort to move toward this critical price point.

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