

DE-COUPLING CLADDING INSTALLATION FROM OTHER HIGH-RISE BUILDING TRADES: A CASE STUDY

Iris D. Tommelein¹ and Greg Beeche²

ABSTRACT

This paper presents a system to handle and install exterior cladding on high-rise buildings. The system is innovative in that the cladding panels are installed from the building's exterior without the use of a tower crane or man lift, and without on-floor staging. Accordingly, all work pertaining to the panels effectively is de-coupled from most other construction work going on concurrently on site. This results in flexibility and work that can progress at a fast, continuous pace, thereby also allowing for project schedule acceleration. The paper includes illustrations of the use of this innovative cladding installation system in the process of constructing the 70-story Trump World Tower in New York City. The system was developed recognizing that tight handoffs between trades may lead to detrimental performance. De-coupling of interacting trades is one step towards implementing a lean construction system.

KEY WORDS

Parade of trades, interacting sub-cycles, de-coupling, exterior cladding installation, curtain wall construction, high-rise building construction, Trump World Tower, lean construction.

¹ Professor, Constr. Engrg. and Mgmt. Program, Dept. of Civil and Envir. Engrg., 215-A McLaughlin Hall, Berkeley, CA 94720-1712, 510/643-8678, FAX: 510/643-8919, tommelein@ce.berkeley.edu, <http://www.ce.berkeley.edu/~tommelein>

² Director of Market Development, Beeche Systems Corp., Scotia-Glenville Industrial Park Building 202, Scotia, NY 12302, 518/381-6000, FAX: 518/381-4613, gbeeche@beeche.com, <http://www.beeche.com/>

INTRODUCTION

One challenge in managing construction projects is to coordinate the work of specialty trades that are on site during overlapping periods of time. Each trade is present for a contractually specified amount of time to accomplish a specific scope of work. While the master-level CPM schedule may identify activities with only finish-to-start relationships, the sharing of resources such as access paths and tower cranes creates interdependence. In addition, uncertainty such as not knowing exactly when another trade will perform exactly what work—to name but one of many—exacerbates the problem. If not managed judiciously, interdependence and uncertainty will lead to significant deterioration in performance of one or several trades, as well as the system as a whole (Crichton 1966, Tommelein et al. 1999).

Howell et al. (1993) recommend that one step towards improving system performance is to de-couple phases or steps of work so that each can be performed independently of the others and improved using work methods design. A follow-on step then is to synchronize all phases or steps to the greatest extent possible, in order to achieve continuous flow (Ballard and Tommelein 1999). Throughout this effort one must assess whether all phases or steps in the system are needed and performed by the party best suited to do so. This is the task of work structuring (Ballard 1999, Tsao et al. 2000, 2001). These steps in combination with others support the implementation of the lean product delivery system (LCI 2000).

To illustrate how de-coupling may get implemented in practice, this paper presents a technological innovation that makes it possible to de-couple the work of several trades involved in constructing a high-rise building. The new system uses temporary structures and specialized equipment designed to handle, stage, and install exterior cladding. The installation of exterior cladding follows the erection of the main building structure. Exterior cladding provides enclosure, the building's skin, which is a prerequisite for much of the work performed by mechanical-, electrical-, plumbing-, drywall-, and other interior trades. Exterior cladding installation comes early in the "Parade of Trades" (Tommelein et al. 1999). Control over this process may thus prevent perturbations downstream.

EXAMPLE APPLICATION: TRUMP WORLD TOWER

The technological innovation presented in this paper was used for the first time to construct the Trump World Tower (Figures 1 and 2). This project is located between First- and Second Avenue and between East 47th and East 48th Street at 845 United Nations Plaza in New York City. It is a 72-story, concrete-frame, and the world's tallest multi-residential building. The slender building, 863 feet (260-meter) high and 146-by-79 feet (45-by-24 meter) in footprint, needed major shear walls. The residential-use and shear-wall requirements led the designer to break up the floor plan of the building. This product design restricted the potential construction process alternatives for the installation of exterior cladding.

Construction of a cast-in-place concrete frame requires assembly and placement of formwork and shoring for columns, walls, and slabs; installation of reinforcing bars; then placement of concrete. On this project, shores were placed 4 feet (1.2 meter) on center and 12,000 psi (83 MPa) concrete was required. After an appropriate initial curing time, formwork can be stripped for reuse on a floor higher up in the structure. The slab is then re-shored to prevent sagging during subsequent curing until sufficient strength is reached for the slab to hold up on its own (e.g., Hurd 1989). On this project, re-shores were placed 8 feet (2.4 meter) on center and they

were removed after 1 month. Limited early-strength of concrete and the presence of re-shores significantly limit floor access. Contractors therefore schedule other trades to lag a number of floors behind the floor where concrete is being placed, so their work will not be unduly obstructed.



Figure 1: Trump World Tower in May 2000.
View to the North (from
<http://members.nbc.com>)



Figure 2: Trump World Tower in New York City
(from http://www.cityrealty.com/building_guide/building/index.page?id=7176)

The construction manager on this \$360 million project is Bovis Lend Lease LMB. Flour City Architectural Metals (Flour City International Inc.) won the \$19 million contract to engineer, manufacture, and install 375,000 ft² (36,000 m²) of four-sided glazed curtain wall (Realty 1998). Exterior cladding panels can be made in different sizes. Size is determined based on architectural criteria but also based on fabrication and logistics criteria, such as shipping from fabricator to site, on-site staging, and hoisting for final installation. The fabricator and installation contractor therefore must get involved early and provide input into the design development process, before the design details can be worked out. Larger panels allow for faster erection with fewer on-site labor resources, but they require more space for maneuvering and staging, and they are heavier so they require hoists with greater capacity. This trade-off will be revisited later in this paper, with the discussion of alternative cladding installation systems.

The Trump World Tower project broke ground in 1999 and it is scheduled for completion in 2002. The installation of the project's curtain-wall panels was successfully completed in March 2001.

TRADITIONAL SYSTEM FOR CURTAIN-WALL INSTALLATION

The fabrication and installation of cladding for a high-rise building is typically contracted out to a fabricator who in turn subcontracts out the installation work. The specialty contractor responsible for cladding installation traditionally will install curtain wall panels using a rack-and-pinion system combined with a materials hoist. More often than not, the contractor does not provide their own, dedicated hoist but shares the project's tower crane (or man lift) with other trades.

Panels are shipped on edge 4-5 feet (1.2-1.5 meter) wide and typically 4 panels to a pallet, though this depends on the panels' weight and size. The crane lifts a pallet off the flatbed truck and then brings it to the floor where panels will be installed one at a time. While the crane is holding the pallet at elevation and using some kind of cart that may roll out and onto the floor, the specialty contractor then brings the pallet onto the floor area and stages it relatively close to the perimeter of the floor. The location of panels for staging is determined by the fabricator and requires approval by the structural engineer during the design process because the structure must be able to support the pallet's weight.

The crew removes the panels from the packaging and then wedges a selected panel so it can be laid down on a furniture dolly. The panel is rolled to the edge of the floor. It is hooked to a counterweighted crab (a very small crane-on wheels, see Figure 5 for an example) that is positioned one floor immediately above. A worker manipulating the crab then pulls the panel up until it is in position and another worker secures it to the structure.

This traditional way of handling panels on site requires tight coordination of the use of the tower crane. Staged panels occupy perimeter space on each floor that must be left unobstructed by other trades, for the installer will need working room to slide each panel individually to the edge of the floor prior to lifting it in place.

INNOVATIVE CLADDING INSTALLATION SYSTEM

Greg Beeche and Roy T. Scrafford, both with Beeche Systems Corporation developed a new technology for handling and installing curtain wall panels on high-rise buildings. The innovation of their system is to make it possible to install panels entirely from the building's exterior without use of the tower crane (or man lift) or on-floor staging, so that all work pertaining to curtain wall panels effectively is de-coupled from most other construction work going on concurrently on site.

SYSTEM COMPONENTS

The Beeche exterior cladding installation system (henceforth referred to as the 'system') starts by lifting panels off the truck, proceeds with a sequence of other handling steps, and ends with the installation of each panel in its final location.

Off-loading and Staging of Panels

An aluminum space frame grid creates a staging area for curtain wall panels (Figure 3). The grid is erected on columns located on the ground or on a setback roof. The crew (Figure 4 lower-left) can off-load panels directly from the delivery truck. Panels laying down on edge in multi-panel packages are attached to lifting harnesses customized and mounted by the fabricator to specifically match the panel dimensions and shapes. The packages are turned into their final position and then suspended (Figure 4 center) on a trolley-track system attached under the space

frame. The system allows for rapid unloading of tractor-trailers with minimal handling. It eliminates the need to off-load to the ground or to a specific building floor for further handling, thereby minimizing panel damage and enhancing productivity. This is particularly important at downtown, urban construction sites, like this New York City site, where staging space is minimal and dealing with traffic and positioning trucks for offloading is challenging.



Figure 3: Aluminum Space Frame



Figure 4: Panels Suspended from Space Frame

Hoisting and Positioning of Panels

The second main step is to hoist the panels up to specific installation work level. This is done using a crab (Figure 5), which is a versatile, yet relatively small ‘roof’ crane. The crab is positioned on a floor level, successively with 15-story intervals. It hoists panels suspended under the space frame up to the elevation of a monorail system, while making use of a cable-guide system that prevents panels from swaying.

During hoisting, packages of panels are protected from damage through the use of a special hoisting carriage with spring-loaded rollers that ride a cable-guide system (Figures 6, 7, and 9). This guide system is attached to the building structure to keep the panels secure and protected from wind while traveling up the building face.



Figure 5: Crab



Figure 6: Hoisting Carriage and Cable-guide System

After being hoisted up, panels are moved laterally to their installation point using a monorail system, which is attached to the building's columns and wraps around the building perimeter (Figure 8). Curtain wall panels are transferred to proprietary trolley suspenders that traverse the monorail around the building's exterior to the installation point (Figures 7 and 9). The trolleys include hoists for vertical adjustment of the panels for easy installation onto the building.



Figure 7: Walking a Panel (picture from other site)



Figure 8: Corner Detail of Monorail



Figure 9: Hoisting Car



Figure 10: Panel Suspended from Trolley Ready for Final Installation

BENEFITS AND COSTS

The de-coupling of curtain wall erection from other trades' work has numerous benefits.

1. The curtain wall contractor can schedule truck deliveries at their convenience, as opposed to having to coordinate these with the availability of the hoist.
2. This specialty contractor can arrange their offloaded panels and lift them into place as needed, according to their own schedule, that is, independently of any other hoist or tower crane that may have to be shared among different, competing trades. Consequently, the tower crane gets freed up, so other trades' work may also be expedited.

A quick calculation reveals the immediate savings in terms of avoided crane use for the exterior cladding work. On Trump World Tower, 7,800 panels had to be installed. Panels were shipped and hoisted in sets of 4, so $7,800/4$ or 1,940 lifts would complete the 70-story building facade. Assume each package takes about 20 minutes to be handled and assume hoist use costs \$350/hour (a typical range is \$300 to \$600 per hour for using a hoist car or tower crane). This yields a total hoisting costs $\$350/\text{hour} * 1,940 \text{ lifts} * 20 \text{ min/lift}$ or approximately \$226,000.

The GC on Trump World Tower recognized the benefits of de-coupling the cladding system installation from other work by giving about \$200,000 to the specialty contractor as an incentive for them to use the system.

3. This specialty contractor needs only minimal access space on each floor where panels are being installed, as opposed to blocking out tens of feet of perimeter floor space for storing panels prior to moving them into place, thereby hampering other trades' work (e.g., HVAC or plumbing).
4. The avoidance of handling of panels that are stored on each floor also results in a significant decrease in the likelihood of damaging other trades' work (e.g., drywall inside the building) that already is in place.
5. Because access needed to each floor is so minimal, the system makes it possible to install curtain walls on floors of concrete-frame buildings that still have shoring or re-shoring. As a result, curtain wall erection can follow closely behind concrete placement, thereby allowing for an expedited schedule. By contrast, a traditional method for erecting curtain walls would lag significantly behind the concrete work. The system also lends itself well for use on buildings with constrained floor access, such as retrofit projects.
6. The system may reduce labor costs to erect the curtain wall system. These costs are much more difficult to quantify because they depend on labor skills available and the specifics of the alternative methods that may be used.
7. On curtain wall work, breakage of glass is on the order of 5-7% on average. Of the approximately 7,800 glass-and-aluminum panels placed on Trump World Tower, 25 were broken at the time the project was 80% complete. These numbers suggest a significant reduction in breakage and thus avoided rework. Of course, it is impossible to determine exactly what fraction of this improvement is attributable to the innovative system rather than the consequence of other project factors.

Accordingly, the new system results in flexibility and work that can progress at a fast, continuous pace, thereby also allowing for project schedule acceleration.

The costs for deployment of this system are significant:

1. Field personnel on the Trump World Tower project expressed the need for special training of the union laborers that are using the system. As is also the case for many other innovative processes, one needs to learn how exactly to perform all required steps. In addition, the system requires quite a few equipment components and they all need to be cared for. A consequence of using a novel system is, of course, the steep learning curve. A union hall is unlikely to have provided that very specific, specialized training needed to make any one proprietary system work. That also was the case on Trump World Tower. Training of local craftsmen will remain a challenge to the widespread adoption of any new system, including this one. The system itself is rented out to a project, but labor will always be drawn from a geographically restricted pool.
2. The GC's incentive to encourage use of the system constituted about 40% of the equipment rental cost of the system.
3. While the system does not use any other material handling means but its own, it takes time to set up, erect the space frame, mount the guiding cables, and install the monorail. It also takes time to disassemble those components. By contrast, the crab is very easy to move.

4. The efficiency of this new technology depends to a large extent on the ability of the contractor to do the work as they would like to, but other project considerations may govern. For example, the GC asked the cladding contractor to move the monorail up more frequently than was originally intended, so the spacing was sometimes significantly less than 15 stories (this represents a large batch size). Given that moving the monorail from one floor to another takes on the order of one week, this led to a significant increase in setup time.
5. Special consideration must be given to high winds while installing curtain wall panels at the highest levels of the building. This consideration also applies to hoisting using more conventional means.
6. Installation of curtain wall panels for the top floors of the building required a different solution because no monorail could be mounted higher up. In addition, the Trump World Tower design included a major blind wall, so workers did not have floor access to secure panels to the structure.

DEVELOPMENT OF INNOVATION AND OTHER USES OF SYSTEM COMPONENTS

An innovation of this magnitude in scope in terms of the number of required components and their interfaces does not get developed overnight. This system innovation came into being in stages, with the development, deployment, and testing of each component (the space frame, the crab, monorail, and guiding system) over a 25-year period. The Beeche system was nominated for a Nova Award and was recognized as an Award Finalist (Nova 2001).

The space frame has numerous other applications where other kinds of scaffolding may be used, for instance, as working platforms during bridge repair. The crab in and by itself can be used when erecting cladding panels in the traditional way.

Competitors have developed alternatives to, for instance, the space frame and crab. However, to our knowledge, no one but the system presented here has to date fit achieved the same high degree of automation with minimal re-handling.

Plans have been developed to deploy the system on other projects. These include the Borgada project in Atlantic City (10,000 relatively small window panels that will be made double-sized) and two other New York City projects. 731 Lexington has no ground space available for staging and the space frame will be as high as the 9th floor, cantilevered out over the street. Columbus Center-Time Warner Building will use the monorail-and-crab system for the 24th floor and up, where the steel skeleton of the building ends and the cast-in-place concrete starts.

DISCUSSION

PRODUCTION-SYSTEM DESIGN CONSIDERATIONS

Given the design of Trump World Tower, it would have been difficult if not impossible to use curtain wall panels of any significant size and stage them on each floor for installation in the traditional way. Larger panels were fabricated and no floor space was needed for panel staging on this project, because the fabricator and erector were able to develop an innovative installation system. This is of course a chicken-and-egg problem: had this system not been available, panels would likely have been fabricated in smaller sizes. As mentioned, larger sizes allow for increased productivity during installation. It appears that this project will complete 6 months ahead of schedule. The system is said to be a major contributing factor to this success.

The development of this system is based on the recognition that the shared use of the crane constrains the installation of the cladding system as well as other trades. The rhythm of the crane sets the pace of the project. By adding a separate hoisting system, the crane gets freed up so that other trades can use it more and have it available more reliably. Adding another crane to this project would not have been possible. Moreover, offloading of trucks would have remained a challenge.

The system's setup and especially the relocation of the monorail higher up in the structure as the work progresses, define 'batch sizes' for work to be performed most economically. Various project considerations may prevent this most optimal batch size from being feasible, in which case the economics of the system will be less favorable.

The system can hoist materials other than cladding, but such use has been limited, due to the system's cost and the logistics involved in erection and disassembly. Other trades will continue to rely either on the tower crane or on man lifts to bring their materials to the right floor for final installation. They could share the use of the system once the cladding contractor has it in place, but on projects where trade boundaries are strong and all subcontractors fend for themselves, sharing is not an option. Sharing would re-create interdependencies between work that now has been decoupled. From a lean production standpoint, a next step is to aim for continuous flow of work between trades (e.g., Ballard and Tommelein 1999) but even the thought will take a considerable change in mindset over current practices.

OTHER ADVANTAGES AND DISADVANTAGES

Other advantages and disadvantages of the system are the following.

1. The system is not limited in application to concrete-frame buildings. The monorail and guide system consists of equipment that is clamped on to columns so it can be used with steel-frame buildings as well. Shoring is not an issue in that case but spray-on fireproofing may impose a lag between steel erection and cladding installation. Fireproofing on columns may hamper installation of the clamps and be required patching after clamp removal.
2. In the configuration used on Trump World Tower, the system can handle panel loads up to 2,000 lbs (900 kg). Technically speaking, the system can be designed for larger loads as well, but much stricter rigging regulations become in effect once that limit is exceeded.
3. A limitation of the system is that it assumes the building is rectangular and has no setbacks. Using the system on a building with setbacks will require multiple steps for hoisting panels to the upper, recessed levels. Panels flown by a crane could more easily swing to the right location.

CONCLUSIONS

The system for exterior cladding installation, which was presented in this paper, is innovative in that it makes it possible to install panels almost entirely from the building's exterior, without the use of a tower crane and without on-floor staging. Accordingly, all work pertaining to the panels effectively is de-coupled from most other construction work going on simultaneously on site. This results in work flexibility and schedule acceleration.

The system clearly illustrates industry practitioners' concern with dependencies between trades, and managing variability and uncertainty of handoffs in order to improve performance. The presented solution illustrates the advantages of de-coupling work processes, which is advocated by lean production theory for processes that cannot be synchronized. It is exciting to see that theory can explain new developments or innovative practices in construction. Theory might help steer further developments as well.

REFERENCES

- Ballard, G. (1999). "Work Structuring." *LCI White Paper-5*, Lean Construction Institute, June 12.
- Ballard, G. and Tommelein, I.D. (1999). "Aiming for Continuous Flow." *LCI White Paper-3*, Lean Construction Institute, March 5.
- Beeche (1999a). "New Design Dramatically Increases the Performance of Steel Truss Frame System." *Beeche News*, 1 (1) 2.
- Beeche (1999b). "Beeche on Three San Francisco Bay Bridges." *Beeche News*, 1 (1) 3.
- Better (1998) "Technology Conquers Steel Bridge Maintenance." *Better Roads*, November.
- Crichton, C. (1966). *Interdependence and Uncertainty. A Study of the Building Industry*. Tavistock Institute, Tavistock Pubs., London, U.K., 83 pp.
- Howell, G., Laufer, A., and Ballard, G. (1993). "Interaction between Subcycles: One Key to Improved Methods." *J. Constr. Engrg. Mgmt.*, ASCE, New York, NY, 119 (4) 714-728.
- Hurd, M.K. (1989). *Formwork for Concrete*. Special Publication Number 4, 5th Edition, American Concrete Institute, Detroit, MI.
- LCI (2000). <http://www.leanconstruction.org/lpds.htm> visited 4/1/01.
- Nova (2001). *Beeche Exterior Cladding Installation System for High-rise Buildings*. Nova Award Nomination 2001-27, Construction Innovation Forum, Ann Arbor, MI, www.cif.org and <http://www.cif.org/Nom2001/Win01.htm> visited 4/1/01.
- Realty (1998). http://realtytimes.com/rtnews/rtrcmpages/19981020_trumptower.htm visited 3/14/01, Realty Times, October 19, 1998.
- RentSmart (1998). "Beeche Crab-Ingenuity fills a Tall Order." *RentSmart!*, Nov/Dec.
- Tommelein, I.D., Riley, D., and Howell, G.A. (1999). "Parade Game: Impact of Work Flow Variability on Trade Performance." ASCE, *J. Constr. Engrg. Mgmt.*, 125 (5) 304-310.
- Tsao, C.C.Y., Tommelein, I.D., Swanlund, E., and Howell, G.A. (2000). "Case Study for Work Structuring: Installation of Metal Door Frames." *Proc. 8th Annual Conf. Int'l. Group Lean Constr.*, Brighton, UK, July 17-19, 14 pp., available on <http://www.sussex.ac.uk/spru/imichair/iglc8/34.pdf>.
- Tsao, C.C.Y., Tommelein, I.D., Swanlund, E., and Howell, G.A. (2001). "Five WHYs: First Step Towards Work Structuring." Submitted to ASCE, *J. of Constr. Engrg. and Mgmt.*, in review since February.

Ó 2001 Tommelein and Beeche. All rights reserved.