

DEVELOPMENT OF AN INTEGRATED FACADE SYSTEM TO IMPROVE THE HIGH-RISE BUILDING PROCESS

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ABSTRACT

This paper describes an integrated system for facade installation in high-rise buildings, the development of which was guided by lean construction principles. The facade system has components that comprise means to ease material handling, installation, and maintenance. Integrated installation features of the facade system remain as permanent parts of the exterior facilitates and serves the process of building maintenance.

De-coupling of interacting trades during installation has been the main driver in the system's product development process and is a major system advantage. The facade will be installed from the building's exterior and require only minimal on-floor work, allowing other contractors on site to use the space inside the building. The number of fixers needed when building with the integrated installation system will be significantly lower than with a traditional facade system. Using this system, panels can be handled and installed with a continuous flow that is less prone to variation and generates less waste, such as internal transport and waiting time, relative to traditional installation systems.

This paper refers to lean principles as tools to master challenges in the facade installation process, recognizing problems in traditional installation systems such as, e.g., chain reactions caused by delay.

The integrated facade system, including patented technology, is under further development and in preparation for on-site trials.

KEY WORDS

High-rise building, lean construction, material handling, supply chain, waste reduction, de-coupling, variability reduction, continuous flow, cladding panels, facade system

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INTRODUCTION

Installation of glass facades in high-rise buildings can be problematic, e.g., as a result of chain reactions caused by unpredictable availability of cranes and lifts, materials damage, trade interference, and weather, depending on the building site's location (Tommelein and Beeche 2001, Eisele and Kloft 2003).

Lean construction aims to optimize the building process as a whole, in order to create customer value (Alarcon 1997, Howell 1999) while at the same time promoting flow and reducing waste (i.e., not letting activities take place that do not create value). Taiichi Ohno defined 7 types of waste: (1) defects in products, (2) overproduction, (3) inventories, (4) unnecessary processing, (5) unnecessary movement of people, (6) unnecessary transports and (7) waiting. Waste is a failure to meet the customers' unique requirements. It stems from: "*an activity that uses resources without creating any value for the customer and added design of goods and services that fail to meet customer needs*" (Womack and Jones 1996). Literature reveals plenty of evidence of waste in construction (Koskela 1992, Forsberg and Saukkoriipi 2007).

According to facade contractors, coordinating the facade installation with other contractors' activities is a challenge. Uncertainty about when or where trades will work aggravates the circumstances. Also, it is a challenge for contractors to define and communicate their needs to their suppliers and subcontractors (Friblick 2001). Sacks and Goldin (2007) showed that fluctuations in the number of workers from subcontractors are common in construction projects. Howell et al. (1993) recommend that one step towards improving system performance is to *de-couple* phases of work so that each can be performed independently of others. Synchronizing steps aiming for continuous flow, investigating whether all steps are needed and if planned contractor is the one best suited to perform the task are aspects of work structuring (Ballard and Tommelein 1999, Tsao and Tommelein 2001).

De-coupling means that specific activities are lifted out from the *Parade of Trades* (Tommelein et al. 1999) in the building process. The *Parade of Trades* describes a process with activities that immediately follow one another, and where the successor depends on the output of its predecessor (Tommelein et al. 1999). When activities depend on predecessor activities specified with a finish-to-start relationship, the successor cannot be carried out before its predecessor(s) is (are) completed (Goldratt 1997). If one specific contractor has not finished their contractually specified work, the result might be that the building process has to be put on hold, discussed by Crichton 1966. An interviewed site manager says that: "*The largest risk of delays in our facade installation projects are caused by other trades interfering with our installation work.*"

Problems like these can be reduced by de-coupling the facade installation from other construction work, while at the same time reducing variability and waste (e.g., internal transport and waiting time), resulting in continuous flow for installation work.

This paper explores in more detail the typical issues related to the installation of unitized curtain walling and how to overcome these using Lean Construction.

TRADITIONAL FACADE SYSTEMS FOR HIGH-RISE BUILDINGS

The installation of cladding for high-rise buildings is typically contracted out to a fabricator who in turn subcontracts out the installation of the facade (e.g., Tommelein

and Beeche 2001). Traditionally, curtain wall panels are installed using a material hoist and some kind of lift. Critical resources are vertical transportation, such as tower cranes and main goods lifts, used by the different contractors of the project. These resources and their characteristics with regard to Lean Construction principles are described by the Construction Indices model as follows. Figure 1 presents a model that identifies five *High-rise building constructions Condition Indices* (C_{in}):

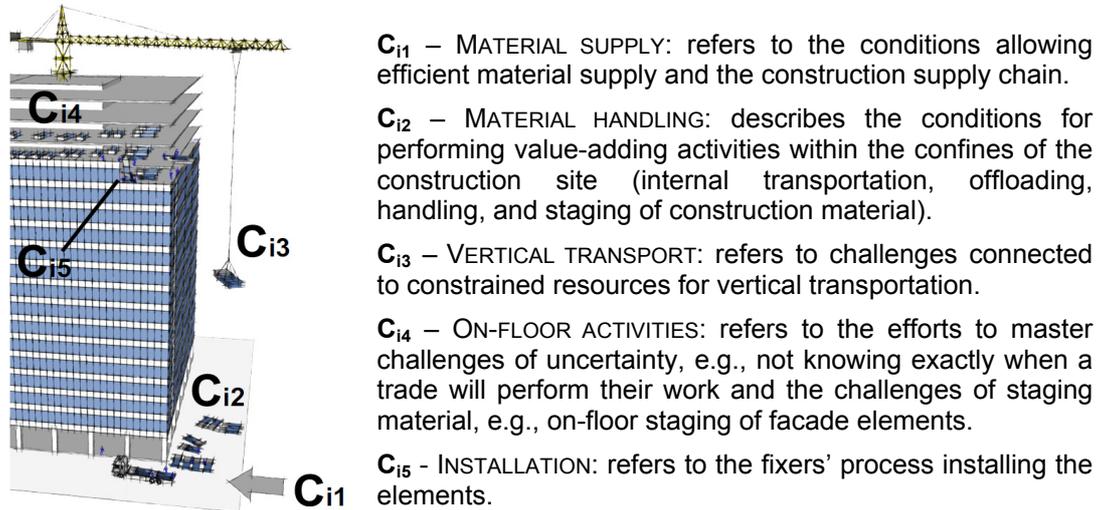


Figure 1: High-Rise Building Construction Condition Indices (C_{in})

Unitized facade panels are transported on pallets depending on size. These pallets are traditionally off-loaded from the delivery truck by crane and then lifted to the floor where the panels will be installed (Tommelein and Beeche 2001). The crane lifting pallets off the truck is critical as for C_{i2} as well as C_{i1} ; waiting time for trucks and tower crane generates waste and substantial costs. *“Transport of frames is the most critical element of managing a project. If the PM gets it wrong, the job always ends up losing money”* says an experienced facade expert (Scicluna 2009). The lifting itself is a critical C_{i3} -activity; it calls for coordination of use of the tower crane. *“Any builder welcomes the chance of having his building less relying on the crane time. Down-time of crane time can cause havoc on a building programme.”* (Scicluna 2009)

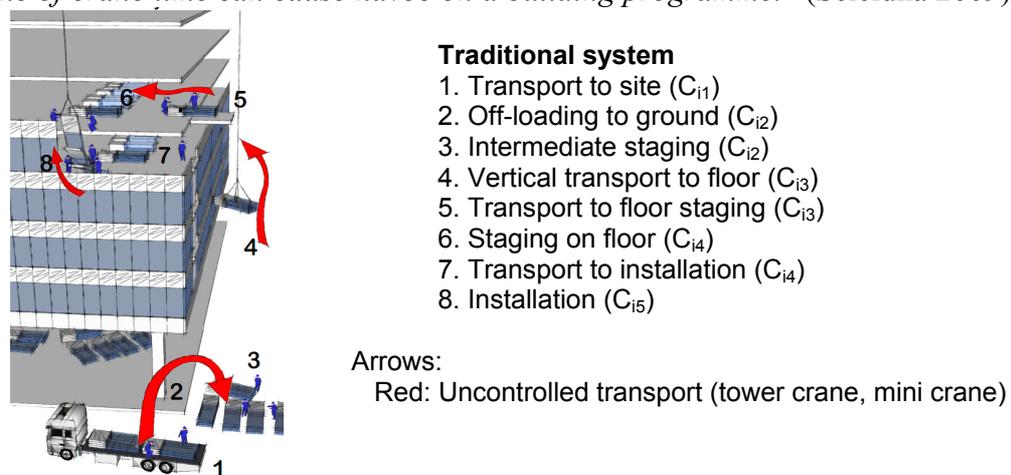


Figure 2: Work Flow for A Traditional Facade System

The on-floor staging of panels is a major C_{i4} challenge, since staged panels occupy space on each floor that must be left unobstructed by other trades, and the installers need working room to handle each panel at the edge of the floor when lifting it in place (Tommelein and Beeche 2001). The positioning of panels on the floors is also critical and requires detailed instructions from the structural designer; as the physical structure must be able to support the weights of the pallets. Limited early strength of concrete and re-shores limiting floor access are important C_{i4} aspects.

Tommelein and Beeche (2001) describe an innovative system for handling and installing exterior cladding. By de-coupling the cladding installation from other trades, lead times and costs can be reduced⁵. The general contractor on Trump World Tower recognized the benefits of de-coupling the cladding system installation from other work by giving \$200,000 to the specialty contractor as an incentive for them to not use a tower crane but instead use the so-called Beeche System (Tommelein and Beeche 2001). In the Beeche system, 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. The monorail was supposed to be reinstalled every 15th story but the general contractor wanted to reinstall it more frequently, which increased the setup time. (Tommelein and Beeche 2001)

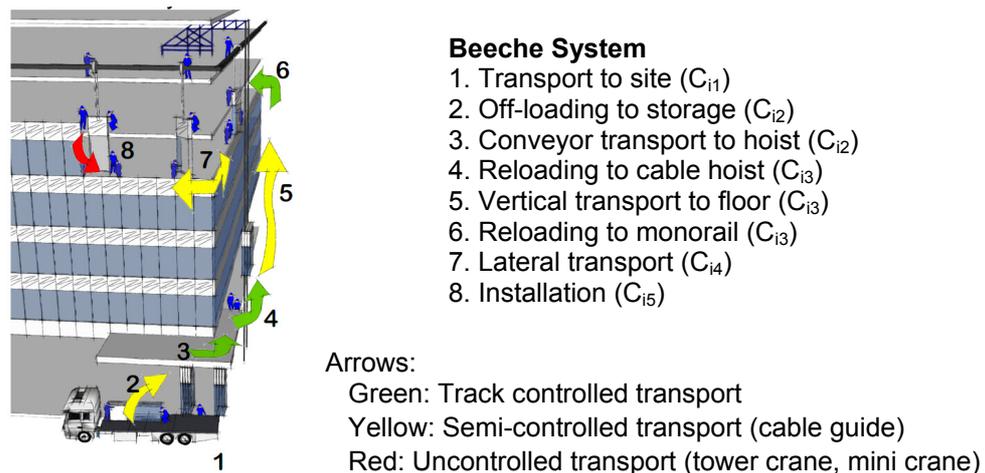


Figure 3: Work Flow for the Beeche System

Regarding damage on facade elements, industry practitioners estimate that 5-7 % of glass elements get damaged throughout installation of a glass facade. Building the Trump World Tower the percentage of damages was reduced to 0,32 %⁶, according to calculations from Tommelein and Beeche (2001). The Beeche system results in flexibility (e.g., C_{i3}) and schedule acceleration (C_{i4}). Due to the increased productivity, it appears according to Tommelein and Beeche (2001) that the project finished months before scheduled time.

On-site activities relating to facade installation should be reduced as much as possible in the supply chain (C_{i1}): they should take place in the controlled environment of a factory, instead of the uncontrolled environment on the building site.

⁵ Nova, 2001

⁶ 0.32 % was measured when 80% of the facade was installed.

Facade product development efforts therefore have focused on prefabrication, performing as much assembly as possible before the facade elements arrive on site, avoiding impact of weather conditions during installation and benefiting from regular and timely delivery of required components. (Eisele and Kloft 2003).

INTEGRATED FACADE SYSTEM FOR HIGH-RISE BUILDINGS

Brunkeberg Industriutveckling AB, is in the process of developing a patented facade system, *the BI System* (henceforth referred to as the integrated system) that enables an efficient process for facade installation. The system comprises techniques for material handling, installation, and maintenance that illustrate the use of lean construction practices. Lean thinking has been used to master challenges in the construction process, recognizing the aforementioned problems in high-rise buildings such as chain reactions of delay. The system aims to control the material flow and - as an additional feature - incorporates equipment for facade installation to serve future maintenance as a permanent part of the building.

By design, the system allows for waste reduction in the building process: facade installation is decoupled, and can thus progress separately from other trades' work, while itself proceeding in a continuous flow process (e.g., Womack and Jones 2002). Various kinds of waste are reduced, for example:

- *Inventory* – No on-floor staging (C_{i4}) will be needed since facade elements are transported via the system directly to the elements' installation positions or to their dedicated staging area, thereby not affecting space on the ground or inside the building.
- *Transportation* – On-site transport will be minimized by lifting the facade elements directly from the truck onto the system and forwarding them to their installation positions, without any interim on-floor staging. This avoids internal transportation.
- *Waiting* – Installing the facade system independently of the site crane and hoist, and freeing up floor space area for others, reduces the waiting time for the facade installers and for other contractors.
- *Defects* – Risks of damaging the facade elements will be reduced given that no on-ground or on-floor staging is necessary and that there is full control over on-site transports using fully integrated equipment.
- *Motion* – The system will have equipment that handles the material flow through the whole process; from factory to installation point. Thereby, contractors will not be subject to unnecessary handling or reliance on potentially unsuitable lifts.

The system is intended for large curtain wall facades and has integrated support for optimized logistics as well as optimized installation and maintenance according to the principles of lean construction. It is an innovative system designed to enable decoupling of the facade installation process from other site activities. De-coupling of interacting trades has been the driver in this system's product development process in order to meet C_{i4} challenges and reduce the usual uncertainties encountered during the traditional high-rise building process.

Installation of the facade no longer has to depend on previous activities, for example, facade installation could proceed from the exterior independently from, e.g.,

the early strength of concrete, re-shoring, and waiting for lifts or other trades. The system is installed from the building's exterior, requiring only minimal on-floor work, thereby allowing other contractors on site to use the space inside the building. The system allows the edge protection at the perimeter of the floor slabs to remain in place during panel installation, thereby improving site safety. Also, the system handles all the facade panels' transportation, which means that the facade contractor is virtually independent of the site's common shared cranes and building hoists, making the cladding installation independent of C_{i3} aspects.

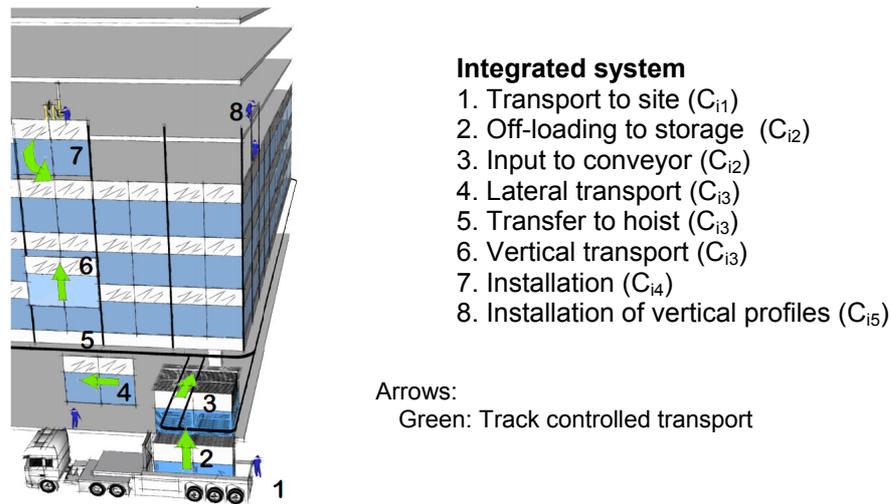


Figure 4: Work Flow for the Integrated System

COMPONENTS AND SUBSYSTEMS OF THE INTEGRATED SYSTEM

Vertical profiles - Vertical profiles are designed to fulfil a dual function: they act as support for the facade panels and as guides in the transport system during installation and later maintenance of the facade.

Adaptor - An adaptor profile enables the use of any proprietary curtain walling system with the new installation system.

Conveyor System (for lateral handling of facade elements) - A conveyor system, mounted onto the building frame on all sides, serves as a temporary system for lateral handling of facade panels during the installation. The conveyor system consists of equipment for unloading facade panels from the delivery truck, staging of facade panels (if desired) in a staging area, lateral transport of facade panels from the staging area to the appropriate wall section, and reloading of the facade panels for vertical transport to the installation position in the facade.

Hoisting device - The hoisting device is a flexible and compact crane on wheels. In transport mode, it will be moved manually between wall sections. In operation mode, it will be anchored to the floor and the ceiling with for example a hydraulic shore. The hoisting device will also be used to move the facade panel lift between different wall sections on the floor.

Panel lift - A facade panel lift runs along the vertical profiles. The lift is suspended and moved vertically with the hoisting device that is positioned above the floor where facade elements are being installed.

Staging device - A staging device is provided for external access if desired. It has

vertical guides sliding in the vertical profiles and it is lockable at any level. The staging functions as a safe working platform. It can also be equipped with weather protection. Options: The vertical rails create a permanent support system for exterior solar shading, advertising banners, and for other future new technology applications.

Trucks - Specially adopted trucks will allow direct connection for offloading to the conveyor system upon arrival on site.

CASE STUDY

A reference group of consulting engineers⁷, specialized in curtain walling design, compiled detailed information about cost drivers and challenges for a high-rise reference building, relative to which the advantages of the integrated installation system are assessed. In addition, two high-rise buildings⁸ in Sweden have been studied in order to simulate the use of an integrated installation system. Site engineers and site managers identified factors and criteria to consider when choosing a cladding system for the construction of high-rise buildings, and during interviews described workflow and significant features for the erection of the building.

The reference project is an Australian building, 126 Phillip Street in Sydney, designed by Foster and Partners. The building has a geometry that is suitable for an integrated installation system. It was chosen because it was recently built and relevant data for a comparison was made available by the main and facade contractors; Bovis Lend Lease and Permasteelisa.

FACADE INSTALLATION

The facade installation for the reference building was estimated to require 4 days/floor, but an allowance for inclement weather and disruption of 1 day/floor was added to provide more programme certainty. Installing the facade using an integrated installation system would not require this additional allowance. The industrial process, sliding elements up the exterior of the building, would speed up the installation reducing the time required by 20% just by avoiding this extra allowance.

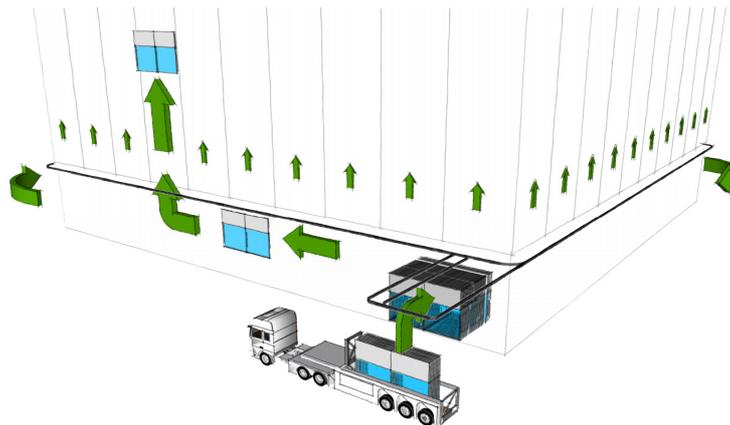


Figure 5: The Process Path of Elements being Slid Up on to the Building's Exterior

⁷ Arup Facade Engineering

⁸ Kista Science Tower in Stockholm, Sweden and Gothia Towers in Gothenburg, Sweden

The numbers of fixers needed when building with the integrated installation system will be significantly lower than building with a traditional facade system. When building the reference building, 21 fixers were needed throughout the façade installation. Rough calculations show that the number of fixers needed when building with the integrated system could be cut by half, at least. At this moment developers estimate the number of fixers needed at nine, or possible even fewer.

A preliminary calculation comparing the reference building's overall facade cost with the integrated installation system's has been carried out. This calculation indicates that the reference building would have benefit by using an integrated installation system saving of around 5 % of the overall facade cost. Labour costs are reduced in comparison to a traditional high-rise building. However, material costs for the building are greater, but not at a rate letting the total facade costs exceed the reference building's facade cost. Further detailed studies will be conducted, investigating cost drivers and savings. The de-coupling benefits of avoiding chain reactions of delays for other trades have not been taken into consideration in the comparison of facade costs above. Building trade delays are costly, so builders work hard to avoid them. For example, the cost of delay for the Australian reference building was estimated to be \$114,000/ week excluding any contractual penalties for late completion, even though the facade installation started at the beginning of the good weather season.

DISCUSSION

The case study suggests that there would be a clear time and hence cost advantage in using an integrated installation system instead of a traditional one. Such a system could further be designed to provide safe external maintenance access and easy installation of additional features at a later stage in the building's life.

ADVANTAGES WITH AN INTEGRATED INSTALLATION SYSTEM

Comparison of the integrated installation system and the reference building reveals several advantages listed in order of importance:

1. *De-coupling* - The system would enable the whole construction process to be efficient by de-coupling the curtain wall erection from other trades, decreasing the risk of delays. By being able to perform activities in parallel, the project's total duration will be reduced. Time buffers would not be necessary to the normal extent considering that contractors are not depending on each other's work being performed. Continuous flow when installing the panels reduces the need for stock piling on site that is typically needed to compensate for fluctuating demand and to avoid stock-outs. This results in the supply of material to the building site (C_{i1}) being controlled more easily. When Tommelein and Beeche (2001) presented the Beeche system, they emphasized that only minimal space on each floor is required for installation, leaving other contractors' work undisturbed, reducing all contractors' waiting time. This is a great advantage enabling de-coupling, which also is achieved with the integrated installation system.

2. *Control of the material flow* (C_{i1-5}) - The integrated installation system is unique in the way that it handles the facade panels from the factory, through all the stages of transport and to its final position on the building. Beeche and Tommelein (2001) presented the advantage of enabling the facade contractor to schedule

deliveries of material, without taking other contractors' work or equipment into consideration. The integrated system equally allows the facade contractor to do so, delivering just-in-time and independently of crane availability. For the Beeche system, Tommelein and Beeche (2001) estimated savings around \$226,000, not using the crane when installing the facade of the Trump World Tower.

3. *No need for on-floor staging (C_{i4})* - Storing facade elements on respective floor is a problem because it prevents access for other contractors, creating delays. Avoidance of interim storage and minimization of handling reduce the risk of damaging the panels and other contractors' material.

4. *Large facade elements* - A reason for choosing a unitized facade system over a stick system is the possible degree of prefabrication. Prefabrication reduces the need for site work, increasing quality through manufacturing in a controlled factory environment. Increasing element size is often limited by handling and transport issues and facade panels are seldom manufactured in sizes larger than 10 m². The integrated installation system enables safe and speedy installation of large panels.

5. *Less sensitive to wind* - In general, installation of the facade is sensitive to wind and might have to be put on hold when it is too windy. According to the site manager at Gothia Towers, time buffers are used in the installation programming to ensure that the overall programme is maintained. The integrated installation system solves this particular problem by permanently guiding the facade panels in static tracks rather than relying on swinging cables. Traditional curtain wall methods normally use facade element sizes with a width around 1.2-1.5 m, which suits on-floor traditional methods. With the integrated installation system, considerably larger facade panels can be installed without requiring a tower crane.

6. *Less transport* - Figure 6 shows the environmental advantages with the integrated system's transport solution. The bars present the facades metric length capacity for each truckload.

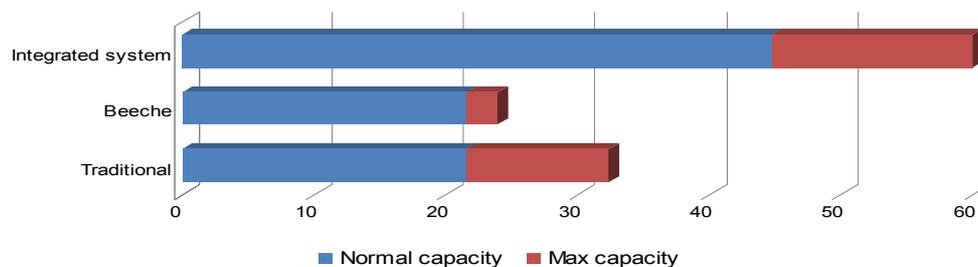


Figure 6: Capacity/ Truckload (Facade Length m)

RISKS TO CONSIDER

1. *Handling and transportation of large facade elements* - There are challenges to be met when handling large prefabricated elements, both in the factory and during transportation. Trucks are constrained by weight and maximum height limits due to tunnels and bridges. Special trucks with lowered floor like flat-liners used for other large prefabricated elements would be needed in order not to exceed height limitations.

2. *Disturbances from other contractors* - There is a risk that other contractors disturb the facade installation. For example, deliveries of elements require access to site near the facade, so that the elements can be offloaded via the conveyor system.

3. *Only one way for transporting panels* - There is only one way to transport the panels on the conveyor system and within the vertical rails and no alternative means of attachment are built into the panels. If components or subsystems break down this may cause delays.

COMPARISON OF CONDITION INDICES (C_m)

Generally, high-rise buildings struggle with problems during facade installation. Indications show that the integrated system may alleviate such problems. Table 1 reflects the authors’ assessment of the (1) traditional facade system relying on a tower crane, (2) the Beeche System, and (3) the integrated system, with regards to the five condition indices. The table visualizes significant differences that can be created by applying lean principles to the facade installation. The integrated system’s advantages can have significant impact, which means a more efficient installation process.

Table 1: Comparison of Condition Indices (C_{in})

	Traditional system					Beeche System					Integrated System				
	(C ₁) Material supply	(C ₂) Material handling	(C ₃) Vertical transport	(C ₄) Minimal floor activities	(C ₅) Installation	(C ₁) Material supply	(C ₂) Material handling	(C ₃) Vertical transport	(C ₄) Minimal floor activities	(C ₅) Installation	(C ₁) Material supply	(C ₂) Material handling	(C ₃) Vertical transport	(C ₄) Minimal floor activities	(C ₅) Installation
Advantage areas															
De-coupling	++					++	++	++	+	++	++	++	++	+	++
Material flow control	++				+	++	++	+	+	++	++	++	++	+	++
Large facade elements	++	+	+		+	++	+	+	+	+	++	++	++	++	++
Low wind sensibility	++	+		+	+	++	++	+		+	++	++	++	++	++

INVESTMENT COSTS

Having carried out preliminary calculations, investment costs for the integrated system are approximately the same as for a traditional system, possibly a few percentages lower. The integrated system though, has major advantages such as less variety in planned activities, less overproduction, less risks, and a higher safety in productivity which are factors that enable reduction of the total contract cost.

CONCLUSION

Glass facade system developers put a lot of effort into developing designs that meet compliances with technical regulations and restrictions. Holistic lean approaches to meet known challenges such as coordination of resources have been few. This integrated system offers an example of innovation guided by lean construction principles. The de-coupling of the cladding installation from other trades enables reduced dependencies between trades, and is an efficient tool to harness uncertainty and variability in the construction process in combination with innovative materials handling. The system could be seen as an important step towards an industrial approach to high-rise building.

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