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# A Novel Façade System to Improve the Whole High-Rise Building Process | 改善高楼营建业工作流程的全新式外观系统


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Henrik Falk has worked in various fields of the building industry as a general contractor and consultant/designer, helping his clients realize their designs. Falk's practical skills as a joiner for high-quality, custom interiors in combination with his design skills and business acumen enable him to identify the opportunities a dedicated façade installation system can offer to various projects.

Henrik Falk 并在营建业不同领域担任总承包商与顾问/设计师，协助客户将其设计付诸实行。Henrik整合优质服务的能力，客制化室内设计，商业敏锐度与设计天分使他体认到完善建筑物外观安装系统所能提供的重大契机。

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Henrik Andersson has spent most of his career in the glass façade industry, including six years at Schüco International, where he was responsible for the Swedish technical department, and six years at Arcus Austraila in Sydney, where he participated in major international façade projects in southeast Asia, such as the Suvarnabhumi Airport in Bangkok and the New Doha International Airport in Qatar.

Henrik Andersson 他职业生涯的绝大部分时间投入于玻璃外观建筑业，包括曾在Schüco International任职6年，负责瑞典技术部门。此外，他也曾在位于雪梨的Arcus Austraila任职达6年，参与包括泰国曼谷素万那普(Suvarnabhumi）国际机场，以及卡塔尔新多哈国际机场等在东南亚进行的重大国际营建项目。

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Fredrik is an assistant professor at Lund University in the department of Engineering Logistics. For 20 years, he has worked in research and teaching construction logistics, starting his company where he served on the board for ten years.

Fredrik 20年来在营建物流领域从事教学与研究工作，并创办瑞典精益工程组织，在该组织理事会任职达10年。Prolog是 Brunkeberg Systems股份公司的合作伙伴，持续将精益生产/工程的基因植入创新系统中，聚焦于营建物流中。

**M. Joop Mul**
Owner/Director | 所有人/主任

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M. Joop Mul started in the general contractor world 30 years ago, specializing in the architectural components that envelope tall buildings in and outside of Europe, from the pre-tender stage up to the execution and maintenance of those projects. Mul has taken part in research projects on the field of technical and logistical matters, especially during the last eight years working for Besix.

M. Joop Mul先生于30年前开始担任总承包商，专精于建筑材质，专攻欧洲内外部营建项目（自接单初期到执行与保修的各阶段）高楼建筑的外壳层设计。他在过去8年为比利时Besix营建集团工作期间，参与技术与物流方面的研究项目。



## Abstract | 摘要

*This paper introduces a façade system integrated with the vertical transportation of building materials and climbing weather protection for the faster and safer construction of high-rise buildings. In the presented case study, the general contractor estimates building a high-rise in half the originally planned construction time with the use of these innovations. The system is designed with a focus on reducing time for projects and, instead promoting flow on construction sites according to lean principles, recognizes the problems in traditional installation systems, such as the chain reactions of delay and high-rise logistical bottlenecks. This weather-independent system is to be installed and run from the building exterior and require only minimal on-floor work. This innovative, climbing weather protection system acclimates the working area, providing a controlled environment for welding and concrete work. The system, including patented technologies, has successful onsite trials and is ready for full commercialization.*



**Keywords: Building Maintainence, Construction, Façade, Façade Access, Modernization, Vertical Transportation**



*关于附有整合式建材垂直运输外观系统，以及针对高楼建筑更安全，迅捷营建上升式天候防护系统之简介。在探讨之个案研究中，总承包商估计：使用上述创新科技，能使营建高楼建筑的原定施工时间减半。系统设计着重于减少时间浪费，并根据精益施工原则提升施工地点的工作流程效率，辨识出传统安装系统的问题(诸如连锁反应造成的延误，高楼导致的物流瓶颈)。这项不受天候影响的系统将被安装于建筑物外观处，并于该处运作，对楼层工事的需求达到最小化。创新性的上升式天候防护设计使工作地点更加适应系统，针对焊接与水泥施工提供受到严密管控的环境。整合式外观系统(包括获专利的技术在内）已在施工现地测试成功，并已准备好商业化量产。*



**关键词：建筑物维护、施工、幕墙、立面开洞、现代化、垂直交通**


## Introduction

On construction sites for high-rise buildings today, there is a constant battle between contractors over the use of lifting equipment (e.g., tower cranes) and space, both on the ground and on floor slabs. This creates logistical bottlenecks and slows down the building process. General contractors are constantly searching for solutions that decouple subcontractors from the use of tower cranes and other lifting equipment.

This paper presents a system of innovative products designed to reduce different types of waste, both materialistic and time related, and promote efficiency in high-rise construction sites according to principles of lean construction. With integrated, vertical logistic solutions, this system not only handles the transportation and installation of unitized curtain wall façades without using ordinary building-site cranes, but also takes over other tasks from the tower cranes, freeing up valuable time for the main task of raising the building's core. All of this happens on

## 简介

在当今的高楼营建业施工中，承包商对起重装置（如上升式起重机）与地面及楼层空间的使用，始终争论不断。这造成物流上的瓶颈，减缓营建速度。总承包商正持续寻求能够使此承包商不再使用上升式起重机与其他升降设备的解决方案。

本论文简介一系列设计于在物质上与时间上减少不同类型废料的产品，并根据精益施工原则，提升高层营建用地效率。通过整合式垂直物流解决方案，本系统不仅不需使用一般营建起重机就能执行组合式幕墙正面安装，还能从塔式起重机承接其他任务，使其获得进行主要任务(建立建筑物核心)所需的宝贵时间。这一切均发生在建筑物的外观上，因而必须将楼层上的工作量最小化，使其他位于现地的承包商能使用建筑物内部的空间。同时将建筑物周边宝贵的地面空间使用量最小化，达成这项目标。

本系统整合对运输用卡车迅速的卸货功能，大幅减少营建用地对周遭区域的负面效应；这一点在都会区特别重要。通过同

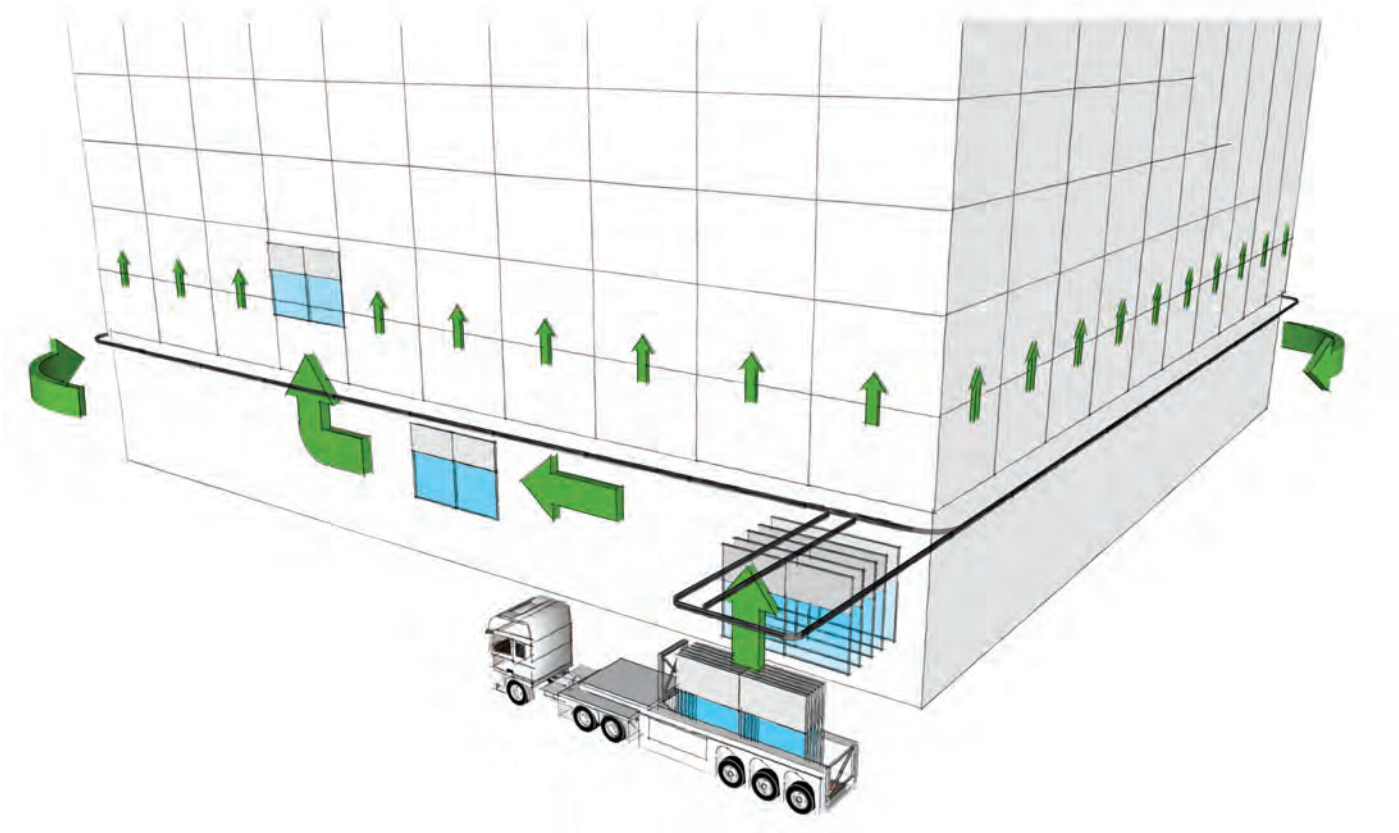

Figure 1. An overview of the system (Source: Brunkeberg Systems)
图1. 系统概观（来源：Brunkeberg Systems）

the building's exterior, and therefore requires minimal on-floor work, allowing other contractors onsite to use the space inside the building. It is also done with minimal use of the valuable ground space around the building.

Combined with the fast offloading of transportation trucks, this system heavily reduces the negative impact that the construction site has on the surrounding area, which is particularly important in urban areas. With the ability to simultaneously minimize the area affected by a building's construction and impact on city traffic, a building project will cause less negative publicity and, instead, get citizens focused on the positive aspects of the project being raised in their city. This paper also includes a case study of how utilizing this system can heavily reduce the construction time of a real high-rise building project planned in Stockholm, Sweden.

## The Façade System with Integrated Vertical Logistics

Brunkeberg Systems AB has developed and patented the Brunkeberg System (henceforth referred to as the system) that enables building companies to increase efficiency, not only for façade installation, but also for all workplace logistics at the building site (Figure 1).

The development started in 2005 by Brunkeberg's inventor Henrik Falk. With a dedication for building logistics, he saw a lot of potential in increasing the efficiency on construction sites for high-rise buildings. First, he gave the system the working name "higher level construction" and during the development of the system, the company Brunkeberg System AB was formed.

The system controls the material in an integrated installation process, from offloading of transportation trucks to final installation location. Curtain wall façade units and customized containers preloaded with goods, such as interior and building materials, are quickly and safely brought right to the specific part of the specific floor the contractor requires. Within minutes of loading the goods into the room, that part of the building's envelope is weather sealed by the installation of the curtain wall façade unit. When the truck arrives at the building site, it stops under an offloading station where the goods are hoisted straight up from the truck into a small hanging storage system located a few stories off the ground. The offloading station can be placed anywhere around the perimeter of the building, or even remotely within a reasonable distance from the building, which means it requires no access to the ground below the façade. Here, each façade element and goods container hang from an individual conveyer trolley and can be transported safely around the building site on

步将受施工建筑影响的区域面积与对市区交通的负面冲击最小化，营建项目将减少其负面风评，使市民转而注意到该建筑为其城市带来的正面效益。本论文亦介绍了一项关于如何借由实际应用，大幅减少瑞典斯德哥尔摩高层营建项目所需施工时间的个案研究。

## 拥有整合式垂直物流的外观系统

Brunkeberg Systems AB(股份公司)已研发出Brunkeberg 系统（下称系统）并获得其专利。该系统使营建公司能够增进外观安装与所有位于施工地点物流的效率（图1）。

2005年，Brunkeberg的发明家Henrik Falk展开研发工作。他致力于改善施工物流，发现许多改善高层建筑施工地点效率的潜能。他先将该系统的操作名称定为“高层施工”，并在系统研发期间，建立了Brunkeberg System AB（股份公司）。

从运输用卡车的卸货到最后安装的位置，本系统通过整合式安装流程管控建材。幕墙正面部件与包括内部及建材等预装于客制化货柜的货物，将能被迅速，安全地摆放到承包商所要求特定楼层的特定部位。数分钟内，将货品安装至房间内，通过安装幕墙正面部件，建筑物该部分的壳层即可密封，不再受天候影响。当卡车抵达施工地点时，它会在卸货站下方停下，货物将从卡车上被吊起，送到离地有数层楼高

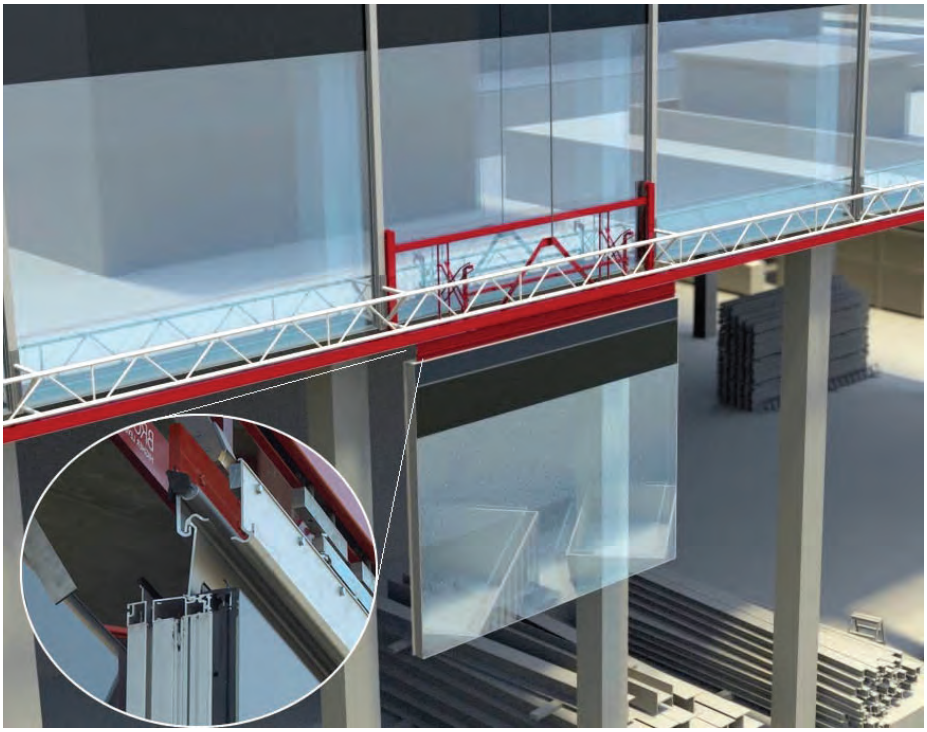

Figure 2. The lifting jig (Source: Brunkeberg Systems)
图2. 升降钩（来源：Brunkeberg Systems）

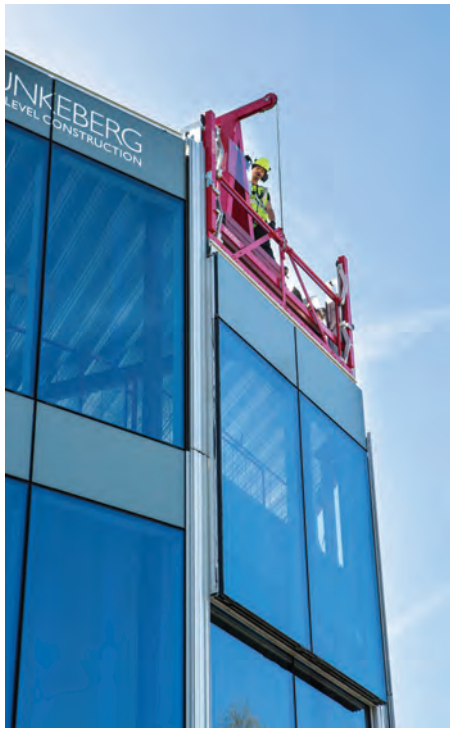

Figure 3. Track-guided vertical transportation (Source: Brunkeberg Systems)
图3. 垂直交通（来源：Brunkeberg Systems）

the system's conveyor tracks. When it is time to transport a façade element or container vertically up the building, a track-guided lifting jig is lowered down by the system's portable crane, operated by the installer, to pick up the unit from the conveyor system and guide it into the system's vertical tracks (Figure 2).

The portable crane then hoists up the lifting jig and its load along the outside of the building with a speed of up to 60 meters per minute (Figure 3). Once the lifting jig reaches the preferred position, the crane operator can safely unload the goods containers or, correspondingly, install the façade element by lowering it down to customized brackets. During transportation in the system, both façade units and goods containers are continuously handled vertically and controlled by the integrated rails which make the system independent from windy weather conditions. The rails are located in the vertical profiles, called wind posts, which are installed (shortly before the façade units themselves) in the vertical joints between the units (Figure 4).

## System Components

- Wind posts – The vertical profiles are located in the vertical joints between the façade units and fulfill multiple functions. They act as support for the façade units, guiding the vertical transport system during installation, and later maintain the façade while acting as attachments for decorative elements on the building's exterior (Figure 4).

的小型过渡悬挂式储藏系统中。该卸货站可位于建筑物周遭任何位置，或离建筑物有一段合理距离的地点；这意谓着，它不需使用正面下方的地面。各个正面元件与货柜自独立吊运式输送器进行悬吊，并可从营建用地系统输送器轨道，自彼此所在的地点安全，独立地运输。必须垂直输送外观元件或货柜至建筑物时，系统的可动式起重机会降下受轨道导引的升降钩。安装执行者可操作这项器械，自输送系统搭载部件，再将其导引至系统的垂直轨道上（图2）。

可动式起重机吊起升降钩并以每分钟60米的速度沿着建筑物外缘升降（图3）。一旦升降钩达到预定位置，即可安全卸下货柜箱，抑或由起重机操作员将外观元件降至客制化支架上。系统的内建式轨道持续从垂直角度处理并控制外观部件与货柜。轨道位于垂直剖面上，称为风标，位于外观部件之间的垂直接合点上。它们在外观部件受安装前，进行安装。

这些轨道不仅使系统免受多风气候的影响，次承包商亦能对彼此采取增值措施，允许平行操作流程，减少前置时间（图4）。

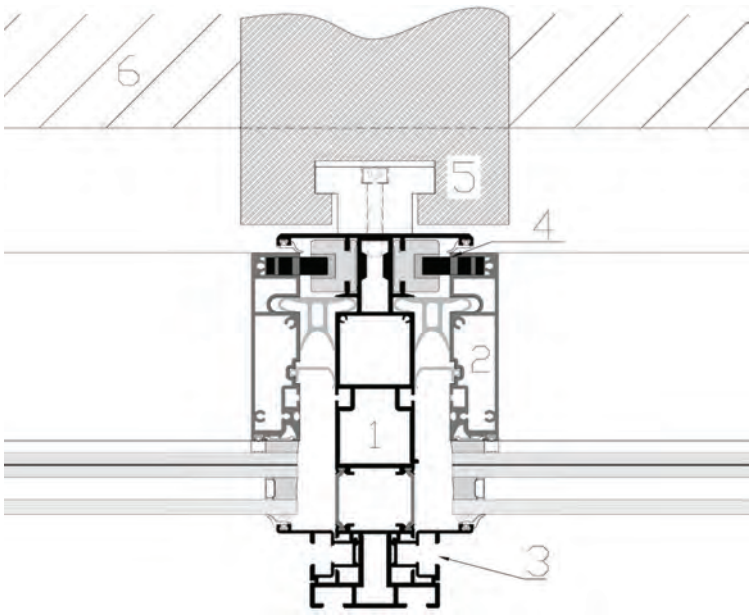


Figure 4. 1) façade bracket, 2) fall protection fence attachment, and 3) bracket for climbing weather protection The horizontal cross section: 1) wind post, 2) façade unit, 3) guiding track, 4) bracket between façade unit and wind post, 5) façade bracket, and 6) floor slab (Source: Brunkeberg Systems)
图4. 1. 外观支架 2. 附加式防坠围栏 3. 上升式天候防护设计支架
水平截面：1. 风标 2. 外观部件 3. 垂直轨 4. 外观部件与风标之间的支架 5. 外观支架 6. 楼板（来源：Brunkeberg Systems）

- Conveyor System (for the Lateral Handling of Façade Elements and Containers) – A conveyor system, mounted onto the building frame on all sides, serves as a temporary system for the lateral handling of façade units and goods containers during installation. The conveyor system consists of equipment for offloading units from the delivery truck and transporting them to the appropriate façade section. If desired, there is also an option to have weather-protected hanging storage integrated in the conveyor system between the offloading station and the façade installation.

- Portable Crane – The compact, flexible crane is customized, developed, and manufactured for the system. It is transported around the building on wheels. In transport mode, it is moved manually between wall sections. In operation mode, it's lowered down from the wheels so that it stands stable on the floor slab.

- Lifting Jig – The lifting jig transfers façade units and containers from the conveyor to the vertical rails and then handles the vertical transport to the installation position in the façade. It is suspended and moved vertically by the crane, which is positioned above the floor where façade elements are being installed (Figure 2).

- Trailer – Inloader trailers will allow direct connection for offloading to the conveyor system upon arrival onsite.

- Goods Containers – Specially designed containers are transported in the system in exactly the same way as the façade units. These are weather-proof and have three hard sides and one open-able side facing the building to allow easy loading and unloading of goods (Figure 5).

- Climbing Weather Protection – The climbing weather protection keeps the floors free from rain and snow until the façade installation takes place. It is designed to run around the perimeter of the building and is located between the current top floor of the building and the floor where the façade is being installed, meaning it climbs up at the same pace as new floors are added to the building. This creates a stable environment inside, allowing concrete to dry and welding to be done in a controlled manner. It also gives the construction workers a safer and much more comfortable workplace. With the climbing weather protection in place, the floor inside the building will be nice and dry by the time the logistics and façade installation crew reaches it. Therefore, goods can be moved into the building directly before the façade installation without risking being damaged by elements, such as moisture. The large surface on the outside of the weather protection can be a lucrative place for advertising (see Case Study). The size, combined with its location on the outside of a high-rise building, makes it visible for large amount of people. Adding advertising to the weather protection can generate income far higher than the cost of the weather protection itself, meaning that instead of a discussion between the main contractor and the contractor of the system regarding how to finance the weather protection, the discussion turns into how to share the profit from it.

- Façade Brackets – The façade brackets in the system have three functions: first, to secure the façade to the building; second,

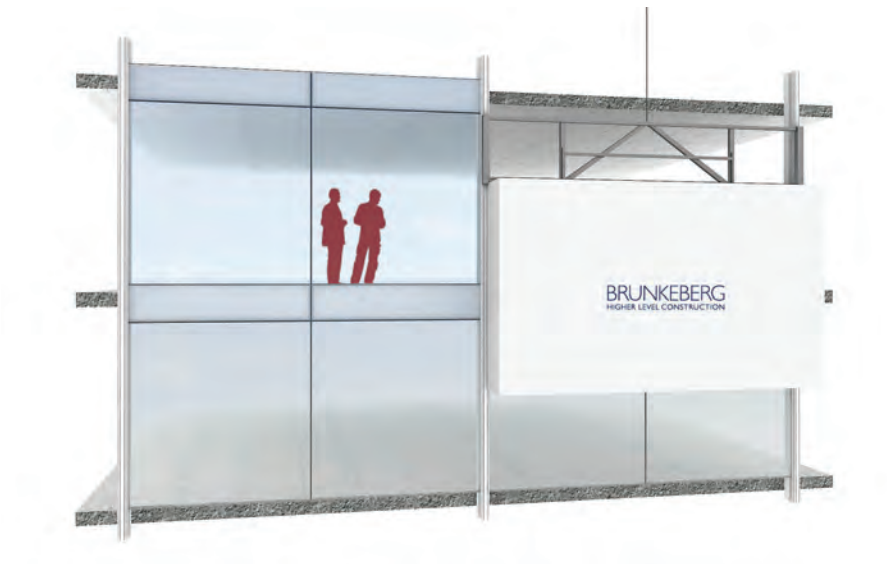


Figure 5. Container logistics (Source: Brunkeberg Systems)
图5. 货柜物流（来源：Brunkeberg Systems）

## 系统零件

- 风标–其垂直剖面位于外观部件之间的接合点上，能满足多重功能。它们作为外观部件的支撑，在安装期间导引垂直运输系统，稍后并能用于外观的维护，并在正面外观处附加装饰性元件（图4）。

- 输送系统（用于横向处理外观元件与货柜）– 安装于各边建框上的输送系统，可在安装期间作为横向处理外观元件与货柜的临时性系统。输送系统由能从载货卡车上卸货的设备所组成，并将它们运送至适当的外观部分。如有需要，亦能选择装设防护各种天候的悬挂式储藏柜。它与输送系统整合，位于卸货站与外观安装点之间。

- 可动式起重机– 结构紧密，灵活的起重机经过客制化，针对本系统所研发与量产。它以车轮在建筑物周遭输送。处于输送模式时，须以人工方式将它在各墙段之间移动。处于操作模式时，它从车轮上降下，并借此在楼板上立稳。起重机亦用于在楼板上不同的墙段间，移动升降钩。

- 升降钩–升降钩将外观部件与货柜从输送器运到垂直轨道上，而后垂直运输到外观的安装位置。它受起重机垂直移动与悬挂，位于楼板上，可借此安装外观元件（图2）。

- 拖车 – 抵达施工地点后，装货用拖车能将卸货过程与输送系统直接连接。

- 货柜– 经过特殊设计的货柜，在系统中的运输方式与外观部件完全一致。它们能在任何天候下操作，其中3面材质坚硬，另一面则采开放式设计，面向建筑物，使货物的装卸更加便利（图5）。

- 上升式天候防护设计– 上升式天后防护设计使楼板在外观安装进行前免受雨雪侵蚀，以稳定的速率及精确的生产节拍时间主导各种营建产业内的施工过程。它被设计为在建筑物的周围运转，位于建筑物目前的顶楼与安装外观正面的楼层之间；这意谓着，它上升的速度与新楼层在建筑物上的安装同步。这创造出稳定的室内环境，使水泥能够凝固，并以严格管理的方式进行焊接。它也为施工的工人提供更安全，更舒适的工作环境。上升式天后防护设计就定位后，物流与外观安装团队抵达建筑物内部的楼层时，楼层将会相当干爽且美观。因此，货物能够在外观安装前就直接搬运到建筑物内，而不至于被湿气所毁损。研究已显示，天候防护设计的外层表面，面积宽广，若作为商业广告用途，利润将相当可观（参阅个案研究）。其表面积与位于高层建筑外观的位置，使相当可观的人潮能发现它的存在。在天候防护设计上设置广告时，所产生的收益将远超过其成本，意谓着：主承包商与系统承包商只需讨论如何均分广告所产生的商业利

to secure the climbing weather protection; and third, to connect the personal fall-protection fence (Figure 6). Instead of having the three different subcontractors drilling or casting their different brackets to the building, this can all be done by the system installer, which would reduce the cost for the general contractor. The patented interface between the bracket and attachment of the fall protection fence is two M12 threads in the façade bracket. The general contractor can then decide to include fall protection in the scope for the façade installer, or use a separate contractor to install the fence between the façade brackets.

## Promoting Flow and Reducing Waste

Taichii Ohno, the "Father of Lean Manufacturing," defines seven 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 (Friblick 2009). Waste is a failure to meet customers' unique requirements. It stems from "an activity that uses resources without creating any value for the customer, and the added design of goods and services that fail to meet customer needs" (Womack and Jones 1996).

Today, waste is considered to be a natural part of the traditional construction process, and it is standard to take the waste in to

润，而无需讨论如何担负天候防护设计的成本。

• 外观支架– 系统的外观支架有三大功能。它的首要任务在于确保建筑外观的稳定性。其次在于确保上升式天候防护设计在建筑物上的稳定性，第三项功能为将防止人员坠落的护栏固定在建筑上（图6）。这一切能够由系统安装员独立完成，降低总承包商的成本，而非任由三名不同的次承包商将各自的支架，架设在建筑物上。外观支架内的两道M12螺纹，构成支架与防止人员坠落围栏之间获得专利认证的界面。而后，总承包商能决定是否将防坠落护栏列入外观安装人员的工作范围，或委任个别承包商，在外观支架间安装护栏。外观部件安装完成后，外观支架的临时性附加物将予以拆除，并于建筑物更高处重新安装。

## 促进工作流畅度，减少损耗

大野耐一是精益生产概念之父，他定义出7种类型的损耗：（1）产品缺陷，（2）过度量产，（3）仓储，（4）非必要的工作流程，（5）非必要的人力移动，（6）非必要的运输与（7）等待（Friblick 2009）。损耗，象征着未能达到客户独特的需求。它源自于「一项使用资源，却未能为客户创造任何价值的活动，添加的货品设计与服务亦未能达到客户的要求(Womack 与 Jones 1996)。

今日，损耗被视为是传统营建流程难以避免的一部分，针对营建项目进行支出与时间成本评估时，也必须将损耗列入考量。本系统因应这项挑战，在上述所有领域将损耗最小化， 促使施工场所的工作流更加顺畅:

• 产品缺陷 – 通过排除地面上或地板上陈列货品或外观元件的必要性，显著降低上述两者损坏的风险，并完整监控施工地点的运输确实使用经充分整合的设备。

• 过度量产 – 通过将损坏外观部件的风险最小化，外观承包商即能将闲置部件的生产最小化。

• 仓储 – 由于外观元件与货柜直接通过系统运输至安装位置，因而无需将材料摆设在楼板上，也因此不影响施工位置地面或建筑物内部楼层的空间配置。

• 非必要的工作流程 – 目前，外观部件须通过好几处位于施工地点的临时性储藏场所，才会到达最终目的地。通过使用本系统，处理外观部件的工作流程更加有效率，并通过单件即时系统控制轨迹。

• 非必要的人力移动 – 将外观安装团队成员数从五人减少到两人，意谓着必须上下出入建筑物的总人数减少。对人力的垂直运输常是高楼建筑营建所遭遇到的瓶颈，任何由次承包商所做出减少施工人数的努力，也将为主承包商所乐见。

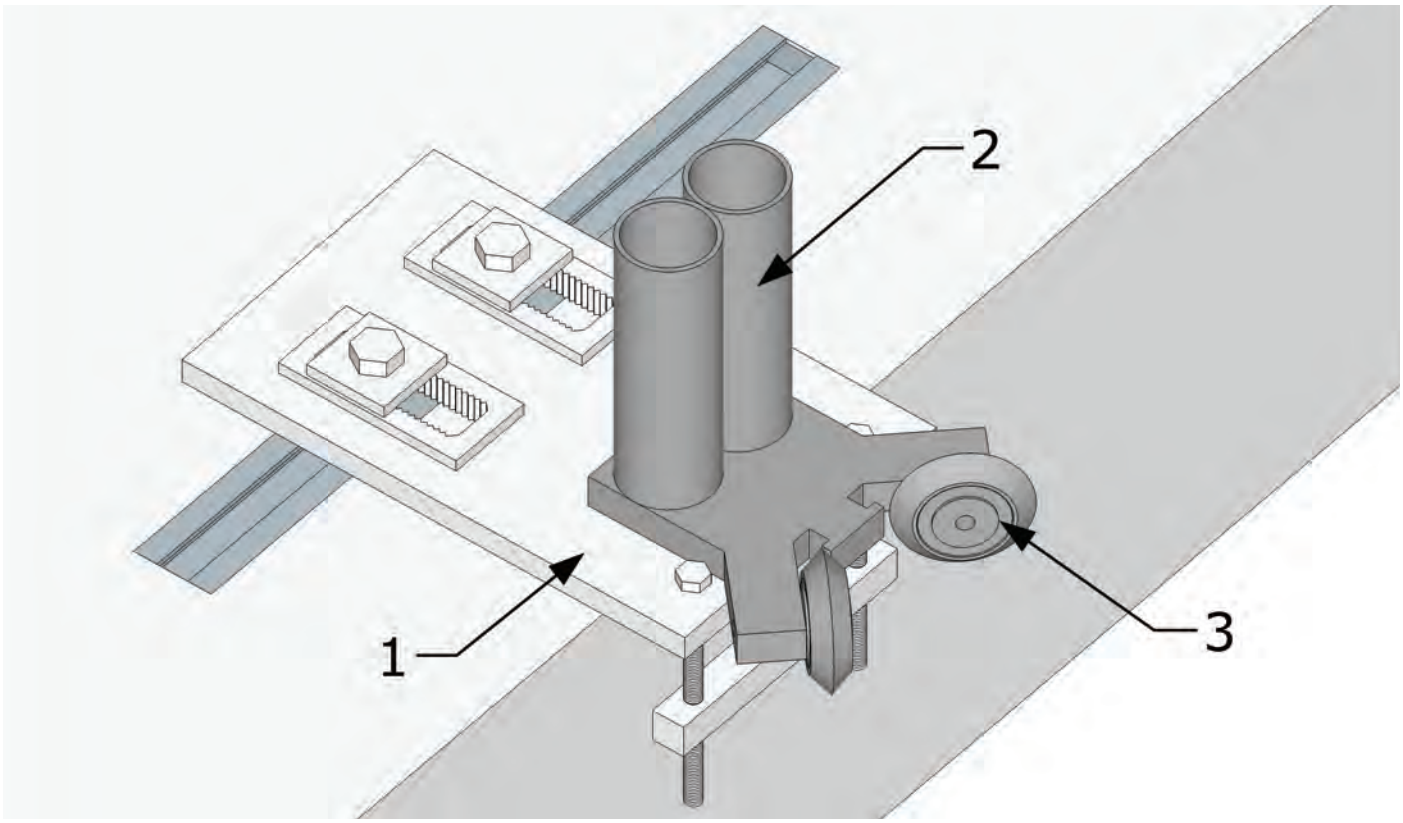


Figure 6. 1) façade bracket, 2) fall protection fence attachment, and 3) bracket for climbing weather protection (Source: Brunkeberg Systems)
图6. 1. 外观支架 2. 附加式防坠围栏 3. 上升式天候防护设计支架（来源：Brunkeberg Systems）

consideration while doing cost and time calculations for a project. The system has stepped up to the challenge to minimize waste in all the areas noted above to, instead, create flow on the building site:

- Defects in Products – The risks of damaging the façade elements and the goods in the containers are radically reduced given that no on-ground or on-floor staging is necessary, and there is full control over onsite transports using fully integrated equipment.

- Overproduction – By minimizing the risk of damaging the façade components, the façade contractor can keep the production of spare components to a minimum.

- Inventories – No on-floor staging is needed since façade elements and goods containers are transported via the system directly to the installation positions, thereby not affecting space, neither on the ground at the building site, nor on the floor inside the building.

- Unnecessary Processing – Today, façade units pass through several interim storage places on a building site before reaching the final destination. Using the system, the process of handling the façade units instead is streamlined and track controlled in a single piece, just-in-time system.

- Unnecessary Movement of People – Reducing façade installation teams from five to two people means that fewer people in total have to be transported up and down the building. Vertical transport of people is often a bottleneck in high-rise construction, and the main contractor would welcome any reduction of the amount of workers required by the subcontractors up in the building.

- Unnecessary Transportation – Onsite transport is minimized by lifting the façade elements and goods containers directly from the truck onto the system and forwarding them to their installation positions, without any interim on-floor staging. This avoids internal transportation and reduces the need for trucks and other smaller lifting equipment on the building site.

- Waiting – Unitized curtain wall façades can be installed in several ways. The tower crane or elevators are often used to transport the units to their installation level, and the installation is then done utilizing monorails or floor cranes. Another common method involves lifting each unit directly from the ground to its installation position using the tower crane. Using the system, both transport and installation of façade units are done independently of the tower crane or building elevators, potentially reducing the waiting time both for the façade installers and other contractors.

Promoting Flow – The system has equipment that handles the material flow through the whole process, from factory to installation point. Contractors are not subject to unnecessary handling or reliance on potentially unsuitable lifts. The system has integrated support for optimized logistics as well as installation and maintenance, according to the principles of lean construction. It is an innovative system designed to make the façade installation process independent of other site activities and equipment. Decoupling interacting trades has been the driver in this system's product development process.

## Case Study

### Introduction

In this case study, the system is assessed and compared with traditional building methods. The reference buildings are two super-slim, high-rise towers – one of 78 and the other of 58 floors – to be erected in Stockholm, Sweden. Each tower has a footprint of 26 meters by 26 meters and a building geometry suitable for the system.

### Façade Installation

Façade contractors normally take into account the fact that windy weather conditions often force façade installation to a standstill. According to a leading façade contractor in Sweden[1] , the estimated wind-caused downtime for tall buildings in Stockholm is normally about 20 percent. Using the system, façade installation is much less sensitive to windy conditions and the contractor for the reference building can remove that factor from the calculations.

Before utilizing the system in the façade design, the reference building was designed with 1.5-meter-wide façade units. After implementing the system, the faced units are now designed to be five meters wide, which is close to the maximum width of 5.4 meters

- 非必要的运输 – 通过将外观元件与货柜直接从卡车运送至系统，再将其输送至安装位置(而无需任何临时性楼板存储)，将施工地点的运输最小化。这能避免内部运输，减少施工地点对卡车与其他较小型悬挂设备的需求。

- 等待 – 单元化的幕墙外观能以数种方式安装。升降式起重机或电梯常被用于将部件运输至其安装水平，并使用单轨或楼层式起重机执行安装。另一常见方式为：使用升降式起重机，直接将各部件从地面上运送至安装位置。通过使用本系统，外观部件的运输与安装不需升降式起重机或建筑物电梯，即可完成。这将能大幅减少外观安装人员与其他承包商的等待时间。

提升作业流畅度 – 系统拥有能在整个工作流程(从工厂厂房到安装地点)中，处理原料物流的设备。承包商不受非必要处理过程影响，更无需依赖可能不适用的电梯。系统针对大型幕墙正面进行最佳化，并根据精益生产原则，整合最佳化物流，安装与保修。这是极富创新性的系统，设计核心在于使外观安装流程能独立于其他施工地点的营建活动与设备。为了打造能在传统高楼营建流程中因应挑战，减少常见未知数的独立性，对互动产业的分离已是本系统产品研发流程的主要推手。外观的安装不再需要依赖起重机的作业时间。

## 个案研究

### 介绍

在此个案研究中，本系统接收评估，并与传统营建方法进行比较。参考建筑物为即将在瑞典斯德哥尔摩兴建，两座极细(高度分别为78楼与58楼)的高塔式建筑。这两座高塔的占用空间均为26米 x 26米，适用于本系统的建筑几何，外观设计与使用模式相互搭配。

### 外观安装

通常，外观承包商会将风大的气候条件迫使外观安装陷入停滞的事实列入考量。根据一名瑞典顶尖外观承包商的说法，[1]斯德哥尔摩因风大而导致高楼施工的停工时间约占百分之20。一旦使用本系统，外观安装受风大气候条件的影响将大为减少，参考建筑的承包商可将该因素排除在外，节省了百分之20的安装时间。

在将系统应用于外观设计以前，参考建筑的设计系由1.5米宽的外观部件所构成。在套用系统以后，外观部件将被设计为5米宽，这已相当接近现行系统版本所允许的宽度上限(5.4米)。 这不仅将建筑物外观所需部件数减少了三分之一，也同步减

1: Fasadglas Bäcklin AB, Stockholm, Sweden
1：Fasadglas Backlin AB（股份公司），瑞典斯德哥尔摩

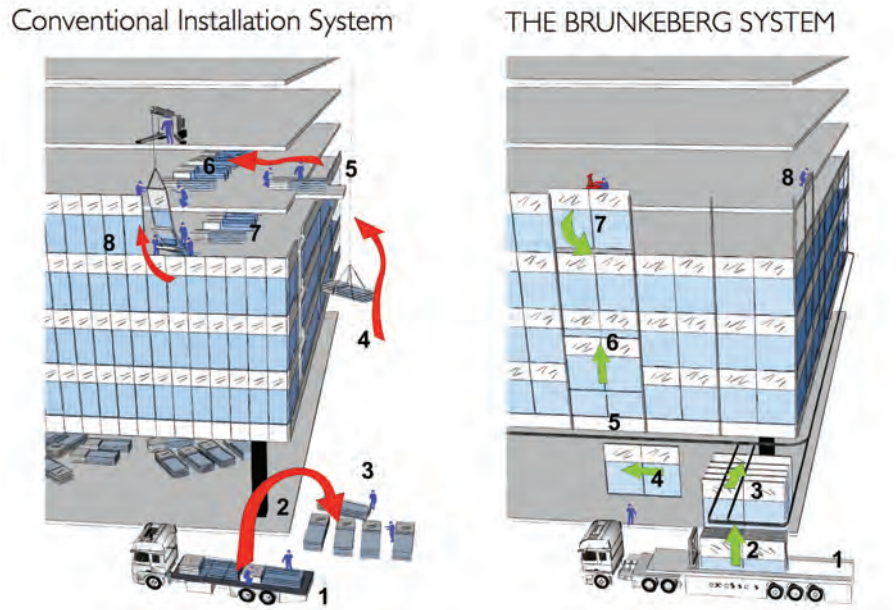


Figure 7. A conventional installation system versus the Brunkeberg system (Source: Brunkeberg Systems)
图7. 传统安装系统：1. 到址运输 2. 地面卸货 3. 居中设置 4. 楼层垂直运输 5. 楼层设置运输 6. 楼层摆置 7. 安装运输 8. 安装 Brunkeberg系统：1. 到址运输 2. 储藏卸货 3. 导入输送器 4. 横向运输 5. 输送至升降钩 6. 垂直运输 7. 安装 8. 安装风标（来源：Brunkeberg Systems）

the current version of the system allows. This reduces not only the required number of elements for the façade to one-third, but also the number of brackets used to attach the façade to the building construction.

The system also reduces the number of staff required from five people, which is normal for traditional installations, down to two people (Figure 7).

An external consultant and expert in construction effectiveness and efficiency (also a co-writer for this paper) monitored a recent project, KTM Motorcycles' Scandinavian headquarters in Örebro, Sweden, that used the system (see Figure 12 ). The study reveals radically improved façade installation performance; for example, the installation was more than 10 times faster than traditional methods (Friblick et. al., 2015).

**Logistics of Interior and Building Material**

Even if façade installation gains many benefits using the system when compared to traditional installation methods, it's when workplace logistics are compared that the system really outshines other methods. On today's building sites, including the reference building, façade units and other building material are transported up the building with cranes and lifts provided by the general contractor. The subcontractors are then allocated specific time slots to transport their material. This creates a situation very sensitive to disturbance and often causes chain-reaction delays. By usage of the system, façade contractors do not have to be limited by the use of the tower crane or any of the general contractor's lifting equipment for façade installation. Parallel to that, the system can transport building and interior material in the customized containers not only to the requested floor, but also to the specific apartment or office. The containers suitable for the building in this case study are 4.8 meters x three meters x 0.8 meters, and can carry goods up to 1,000 kilograms per container. Today, the logistics of transporting these materials normally cost 20 to 30 percent of the value. With the system, these costs would be reduced by at least 50 percent (Figure 8).

**Erection of the Core Structure and Climbing Weather Protection**

Construction of the building's core structure sets the pace for all construction processes in tall buildings. For the reference building, the developer's plan was to build one story per week. After being introduced to the system,

少了用于将外观固定在建筑物施工处支架的数量。

本系统也将传统安装所需的职员数(5人)，缩减到2人（图7）。

一位专精于营建效率与效益的外部顾问(亦是本文作者之一)对一项在近期使用本系统的项目进行检测，研究结果显示：外观安装的效能大幅改善，现行安装的速率是传统方法的10倍以上（Friblick 等，2015).

**内部物流与建材**

与传统安装方法相较，即使使用本系统的外观安装有许多优点，在针对工作场所物流进行比较时，新方法的优点才会真正凸显。在目前的施工地点上(包括参考建筑物)，外观部件与其他建材系由总承包商所提供的起重机与电梯运送至建筑物上。次承包商随之被分配到特定时间区段，运输其建材。这导致系统对干扰与其他由连锁反应导致的延迟非常敏感。电梯设备亦是施工场所的主要瓶颈。通过使用本系统，外观承包商不需在外观安装时，受限于升降式起重机或任何由总承包商提供电梯升降设备的使用。在此同时，受本系统支援的 外部建材工作流使次承包商能够分离作业，通过平行作业提升效率。本系统不只能将客制化货柜中的营建与内部建材运到指定的楼层，还能将其运到特定的公寓房或办公室。本个案研究中适用于该建筑的货柜，规格为 4.8米 x 3米 x 0.8米，每货柜可搭载最重达1000公斤的货物。

当前，运送这些建材所需的物流会导致百分之20到30的贬值率。通过本系统，能将这些支出减少至少50%（图8）。

**树立核心结构与上升式天候防护设计**

本建筑的核心结构营建，足以决定高楼营建的工作流程速率。研发者针对参考建筑制定的规划在于每周兴建一层楼。一名专精于高楼营建的专家在充分了解本系统(尤

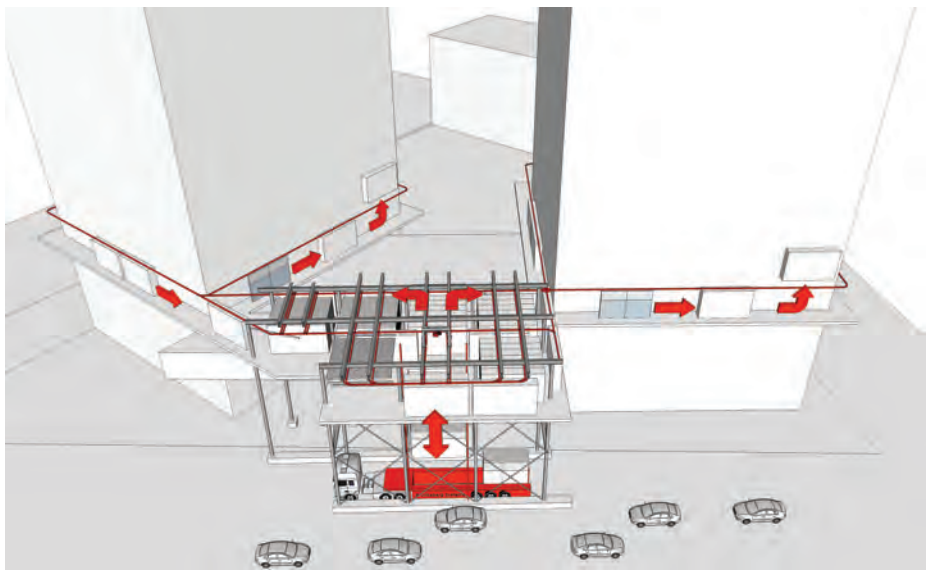

Figure 8. An example of a logistic plan at the building site (Source: Brunkeberg Systems)
图8. 施工地点物流规划范本（来源：Brunkeberg Systems）

Figure 9. Advertising, façade cleaning machine, sun shades, and BMU (Source: Brunkeberg Systems)
图9. 商业广告，外观清洁机，遮阳板与BMU（来源：Brunkeberg Systems）

especially the climbing weather protection, an expert in high-rise construction[2] is confident that the developer can build two stories per week instead – an increase of 100 percent. The reason for this is that concreting, welding, or the assembly of MEP-parts can take place in a weather independent controlled environment, faster methods can be used. The fact that equipment and material can be transported in a container solution less sensitive to wind also speeds up the process.

The advertising on the climbing weather protection for the reference building in Stockholm will, according to a local advertising company[3], generate an estimated revenue of 2.8 million euros during the 24 months of construction. The cost for the weather protection is about 0.3 million euro, which would result in a net revenue of about 2.5 million for the reference project.

### Aesthetics

The reference building was originally designed with 1.5-meter-wide façade units, which results in a view-obstructing mullion every 1.5 meters. After being introduced to the system and the ability to handle larger façade units, the architect has redesigned the façade with five-meter-wide units with wider glass panels to create less-obstructed, panoramic views. Care has to be taken in regards to the weight and strength of the glass panels in relation to wind pressure and, in some cases, a glass dividing mullion will be required.

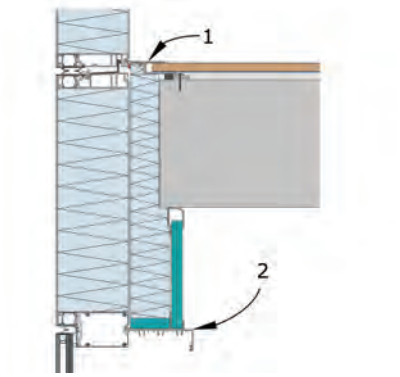


Figure 10. Examples of profiles connected to the XYZ-tracks (Source: Brunkeberg Systems)
图10. 连接到XYZ–轴的支架剖面图例
（来源：Brunkeberg Systems）

### Add-On Products Related to the Façade

- Building Maintenance Unit (BMU) – Tall buildings, including the reference building, require a BMU to be able to reach the outside of the building if a problem occurs. By using the system, the BMU can be redesigned into a lighter and safer version that is secured to the building by the vertical tracks.

- Window Cleaning Machine – Brunkeberg has also developed and patented an automated façade cleaning machine that moves up and down the building securely guided by the systems vertical tracks. The original plan for the reference building was either to use window cleaners hanging in ropes abseiling down the building or to clean the windows from the BMU. By using the system's automatic cleaning machine, the window cleaning costs for the building would be reduced by at least 50 percent, which could lead to increased cleaning frequency.

- Sunshades – When using wind-resistant external sunshades on tall buildings, it's a must to add guiding tracks or wires to handle the wind loads. The system already has guiding tracks and, therefore, saves the extra profiles and work to attach sunshades without the need to puncture the weather seals.

- Advertising Banners – Advertising banners can be added to the track of the system in the same way as sunshades (Figure 9).

- XYZ-Track – The system can also be equipped with patented seamless click-in connections to the building structure and the interiors, such as curtain profiles, and ceiling and floor connections that enable fast and easy fire proofing (Figure 10).

其是上升式天候防护设计）后，[2]相当确信自己能每周兴建两层楼，意谓着将施工效率提升百分之100。 原因在于：当有效压力(MEP)部件的协同，焊接与组合能够在不受天候影响的控制环境下进行时，就能采用更迅捷的方式。设备与建材能在较不受风势影响货柜中运输的事实，也能加快工作效率。

在位于斯德哥尔摩参考建筑物上升式天候防护设计上刊登商业广告，根据一家在地广告社的评估，[3]将能在施工期(24个月内)，产生280万欧元的利润。设置天候防护系统的支出为30万欧元，这意谓着本设计将为参考项目带来250万欧元的净利润。

### 美学观点

参考建筑物最初设计系由1.5米宽的外观部件构成，这也导致每1.5米就出现一道竖框，妨碍视觉效果。建筑师熟悉本系统，并具备处理面积较大外观部件的能力后，便重新设计外观部件，使其由5米宽的部件组成，并加装较宽的玻璃框，以期创造出较不受干扰的全景。考量到风势压力以及特定情况下必需的玻璃制分隔竖框，必须特别注意玻璃框的重量与强度。

### 与外观有关的附加产品

- 营建维修部件（BMU）– 包括参考建筑物在内的所有新式高楼建筑均必须设置BMU，以便在问题发生时能到达建筑物的外部。通过使用本系统，BMU可重新设计为较轻巧，安全的版本，通过垂直轨道牢牢固定在建筑物上。

- 窗户清洁机 – Brunkeberg 研发出一组自动化外观清洁机，并取得发明专利。它能通过系统垂直轨道的导引，安全地在建筑物上进行垂直移动。参考建筑的设计为：通过绕绳下降法使用该窗户清洁机，或从BMU对窗户进行清洁。通过使用系统自动化的清洁机，对建筑物窗户的清洁成本将能减少至少百分之50，也能增加清洁频率。

- 遮阳板 – 在高楼使用抗强风的外部遮阳板时，务必添加导引的轨道或丝线，以调节风力负荷。本系统已设置导引用轨道；因此，系统节省额外的剖面及附加遮阳板的作业，无须刺穿天候密封设计。

- 广告旗帜 – 可使用与遮阳板相同的方法，在系统轨道上安装广告旗帜(图9)。

- XYZ–轴 – 本系统亦可配置连接到建筑物结构与室内设计，附有专利的无缝式点击连接器，例如帘幕剖面，以及能够促成迅捷防火措施的天花板与楼层连线(图10)。

2: Joop Mul, ATB consult, co-writer in this article (see authors bios).
2: JoopMul，ATB 顾问，本文作者（参阅作者简历表）。
3: First sight, Stockholm, Sweden
3: First sight，瑞典斯德哥尔摩

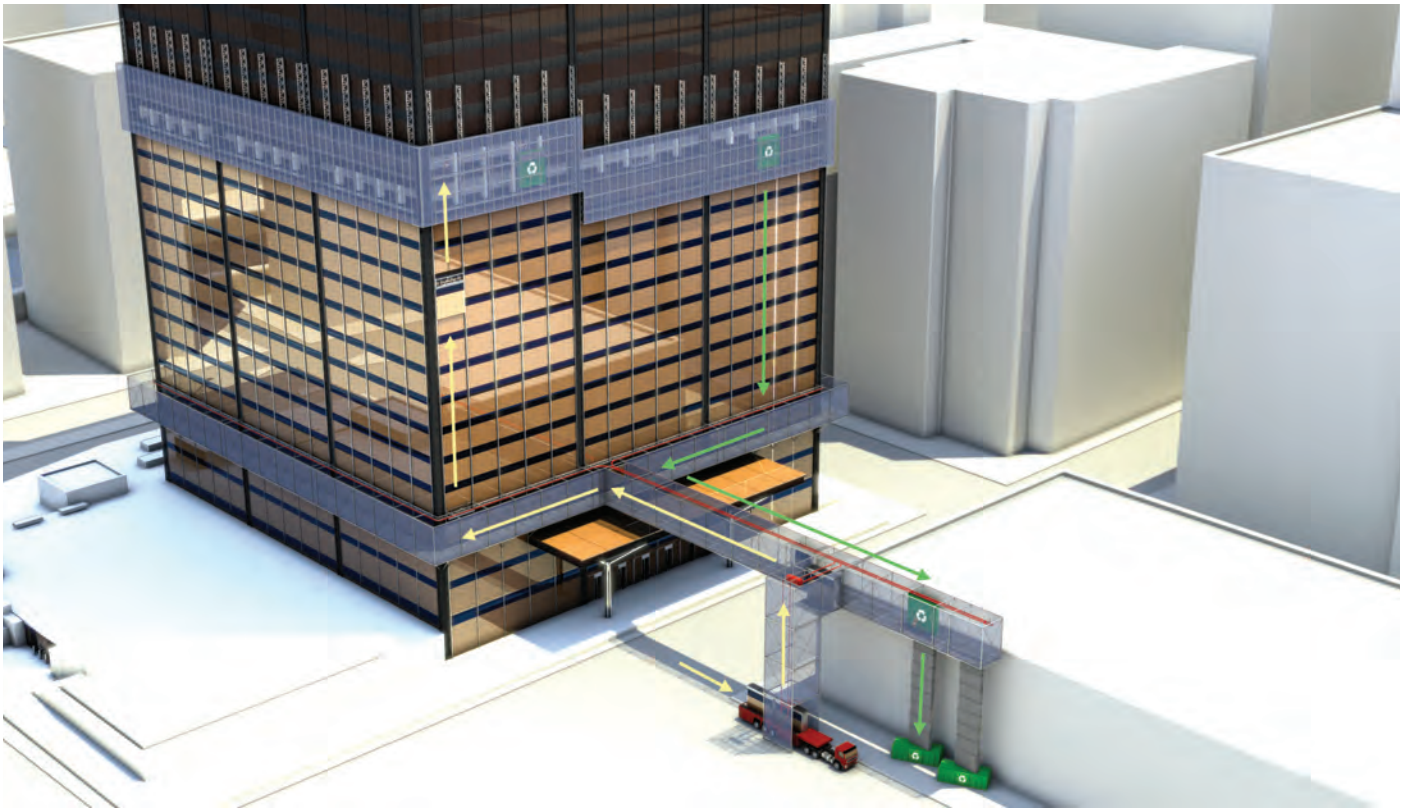

Figure 11. Recladding system work flow (Source: Brunkeberg Systems)
图11. 外包与镀金系统工作流（来源：Brunkeberg Systems）

**Upgradability and Future Proofing**
Innovation in façade technology progresses at a rapid pace, with new designs, materials, and functions being developed every year. The system is designed to meet future needs to upgrade parts of the façade at low cost when the next-generation technology or a redesign is desired. Using the system, safe and simple replacement is available without increasing costs or time for the initial installation.

**Recladding System**
The system can also be used as a unique replacement system for old curtain walls. Its container solution makes it extra suitable for projects where transportation of material and debris is difficult, while speed and safety are also of particular importance.

All curtain walls need to be replaced sooner or later to reduce repair costs, save energy, and increase comfort. The building is typically closed off for a long time, and the tenants need to be relocated at tremendous cost. With the system, the tenants can stay while the recladding takes place from the outside, floor by floor, behind a climbing weather protection. The system facilitates the transport and installation of new façade elements as well as the transport of containers. The containers accommodate debris and panels from dismantling the old façade, as well as materials, tools, or any other components for interior refurbishment that need to be transported up or down. This reduces risks and the need for protective measures associated with handling waste and material through the interior and elevators. A highly automated, controlled workflow maximizes safety and security, and minimizes the disturbance caused by external climbing platforms, building hoists, or cranes (Figure 11).

## Conclusion

The construction industry of tall buildings strives to perform projects in a safe and fast way while also trying to minimize the negative impact caused to surrounding areas and the environment. Designed with these interests in mind, and with the use of lean construction principles, the system enables a faster and safer methodology for both the general contractor during the erection of the core structure, as well as the façade contractor, when installing the external envelop of a building. Adding a logistic container solution that enables more pre-assembly of various components and a fast and safe way of transporting them to the final location, the system is a game changer for the whole construction industry of tall buildings. The system, including patented technology, has been successfully demonstrated in onsite trials, and is ready for full commercialization all over the world

**可升级性与耐受性**
外观建筑技术的革新日新月异，每年均不断推出并研发新设计，建材与功能。本系统设计用于在需要进行新设计或新世代科技时，以低成本满足对外观部分进行升级的需求。通过使用本系统，我们无须增加初步安装的成本或时间，就能取得简易，安全的替代方案。

**外包式系统**
本系统亦可作为替代老旧幕墙的独特系统使用。其货柜解决方案使其非常适合建材与残骸运输不易，而兼具速度与安全性又格外重要的营建项目。

到了一定的时间点，所有幕墙均必须被取代，以减少其修复开支，节约能源，并增加舒适性。通常该建筑会在一段长时间对外关闭，而住户必须重新迁置，代价相当高昂。一旦使用本系统，住户即能在原地居留，重新镀金属的作业亦能在上升式天候防护设计后方进行。建材受到安全的防护，轨道并随时受检查，而无需使用沉重的起重机或上升式平台。它占用较少的地面面积，对周遭环境与交通造成的干扰也较小。本系统的设计适用于安装过程中不受干扰的工作流，并无需使用共享式资源与空间。如此，就能避免连锁反应所导致的延误。

重新镀金过程系由外观底部向上所执行。通常，单元化幕墙的镀金在地面上数层楼处展开，最初数楼的外观则由振杆系统执行。外包式系统不需直接在外观下方的地面上进行作业，而安装在第一层单元化外


Figure 12. Visitors from all over the world experience the system's first commercial project (Source: Brunkeberg Systems)
图12. 来自全球各地的访客，体验本系统所执行的第一个商业化项目（来源：Brunkeberg Systems）

(Figure 12). Thus far, the system is certified for the European market, according to the Construction Product Regulations and Machine Directive. Projects outside Europe would probably require additional certifications depending on which country the project is taking place.

观的输送系统即能处理外观部件的横向运输。上升式天候防护设计为劳工与建筑住户提供受良好保护的环境。同时能使用额外，可动式的内层防护挡板，进一步为住户及内部设计提供防护。

本系统使新外观部件的运输及安装更加便利，也使货柜的运输更加轻便。货柜承装拆除旧建筑外观的残骸与框架，以及必须上下运输，用于内部翻新的建材，工具或其他部件。这减轻了与通过内部与电梯处理废弃物与建材有关保护性措施的必要与风险。

我们将能够安全，有效率地处理最宽达5.4米的大型组合式嵌板。为达到最高质量与最长使用年限，预先组合措施有其必要性。考量到密合处于连接处为幕墙材质最软弱的位置，在经管控的厂房环境(而非混乱的营建施工环境)进行组装，将更能确保质量。

高度自动化，经严密管控的工作流最能确保安全性，并能将外部上升式平台，建筑起吊装置或起重机造成的干扰最小化（图11）。

## 结论

高楼营建业致力于以安全，迅捷的方式执行营建项目，同时试图将对周遭环境造成的负面影响最小化。执行设计时，将这些目的与精益生产原则使用列入考量，本系统能为兴建核心结构的总承包商与安装建筑物外部壳层的外观承包商提供更迅捷，更安全的方法。本系统添加允许各种部件预先组装的物流货柜解决方案，以及将其迅速，安全运达最后地点的工作方式，堪称高楼营建业改变全局的关键推手。本系统(含获专利保护之科技在内）已在施工现地测试中获致成功，并已准备于全球进行商业化量产（图12）。目前，根据营建产品规范与机械指令，本系统已获得欧洲市场合格认证。位于欧洲以外的项目必须根据项目施工所在国家，取得额外的营建认证。

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