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New Skins for Skyscrapers: Anticipating Façade Retrofit

摩天大楼的新表皮：期待幕墙的升级换代

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Abstract

The existing building stock in some regions accounts for nearly as much energy consumption and carbon emissions as the transportation and industrial sectors combined. Existing buildings represent the greatest opportunity to improve on this performance. Early tall building curtain wall applications, not particularly efficient to begin with, are now approaching 40 years of age and more. There is an enormous imminent need for the retrofit of these aging facades that could have significant positive effects. Yet barriers remain. Facade retrofit is expensive and disruptive to ongoing building operations, and these curtain wall systems were never designed to accommodate retrofit. Yet the very same is true of curtain wall design practices today. How do façade retrofit practices measure up with the yardstick of sustainability? Conclusions point to the importance of anticipating future façade retrofit requirements in new building design.

Keywords: Façade Retrofit, Energy Retrofit, Façade Renovation, Façade Preservation

摘要

在有些地区现有建筑的能耗和二氧化碳排放量与交通级工业领域所消耗排放的总和几乎相当。现有建筑在其性能方面展现出巨大的改善潜力。较早的高层建筑幕墙应用，从一开始不是特别的高效，到现在已经近40年或更久了。对这些年久的幕墙提供翻新有迫在眉睫的必要性，从而产生深远而积极的影响。然而障碍仍然存在：幕墙翻新改造是昂贵的，并会打断持续的建筑物营运；而且这些幕墙系统设计从没顾及日后的翻新改造。但是现今的幕墙设计发展也是如此做法。用可持续发展的标尺如何来衡量外墙翻新改进实践呢？最后结论指出了在新建筑设计中所期待的未来外墙翻新改进需求的重要性。

关键词：外墙翻新改进、能耗改进、外墙整修、外墙维护

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Introdcution

In a recent TED conference, popular Danish architect Bjarke Ingels characterized sustainability as a design problem (Anon 2011). Over 60 years ago Buckminster Fuller was talking along an even deeper track, practicing and teaching what he called "anticipatory design science."(Buckminster Fuller Institute 2010) Many of the sustainability issues facing the world today are design problems, and most of these are the result of a failure to anticipate. Consider the building façade.

The Advent of Modern Curtainwall Technology

The birth of contemporary curtain wall technology is found in the post-war high-rise building boom that so rapidly and dramatically altered the skylines of major city centers throughout North America and Europe in the 1960s and into the 1970s, establishing the tall building type that has proliferated to this day. The commercial real estate market eagerly embraced the new building technique of a structural framework supporting a thin skin, largely comprised of glass and metal, and the

介绍

在最近的TED讨论会上，著名的丹麦建筑师Bjarke Ingels将可持续发展列为一个设计问题（Anon2011）。60多年前，Buckminster Fuller谈到了更深的发展轨迹，实践并教授他所称的“预期的设计科学”（Buckminster Fuller学院2010）。现今许多可持续问题都是设计问题，其中的绝大多数都源于缺乏预先准备，考虑建筑物外墙。

现代幕墙科技的来临

当代幕墙技术的诞生源于战后高层建筑的出现和快速增长，大大改变了上世纪六七十年代北美和欧洲一些主要城市市中心的天际线，建立了一直发展到今天的高层建筑形式。商业房地产市场新建筑技术 – 大部分由玻璃和金属构成的结构框架支撑薄身表皮，同时建造业很快的提供服务来回应以满足需求。新的轻质包覆系统曾经在价格上很有竞争性，并且由于与当时传统的石砌相比具有重量轻、深度小的优点，提供了一种对楼层数和每层的出租面积最大化的方法。随着摩天大楼如雨后春笋般出现，这一新兴技术的缺点被传播到至个建筑环境。

construction industry responded rapidly with services to meet the need. The new lightweight cladding systems were cost competitive, and provided a means to maximize both the number of floors and the leasable area per floor because of their reduced weight and minimal depth as compared to conventional masonry practices of the time. The shortcomings of this emergent technology were propagated throughout the built environment as skyscrapers sprang up like new growth after a spring rain.

There were shortcomings. The technology was new. The material suppliers, fabricators, and installers were inexperienced with this new building form (Prudon 2008). The demands on façade systems were minimal; the urban environments of the time were largely commercial centers comprised of office buildings, where commuters congregated during the day to perform their job responsibilities, then returned to their suburban dwellings at day's end. Comfort, as represented by such measures as acoustical and thermal performance, was a lesser consideration (Fitch & Bobenhausen 1999). Most of these early tall building facades were single-glazed. Air infiltration and even water penetration were common problems.

In short, the curtain wall systems installed on these early tall buildings were not great performers to begin with, and some are now approaching 40 years of use and more. Many of them do not conform to today's building code requirements, and some may even present a life-safety threat in the face of escalating storm activity resulting from climate change. Clearly, there is a vast potential need for the façade retrofit of these older tall curtain wall buildings (see Figure 1).

Figure 1. The Sears Tower (aka Willis Tower), completed in 1974, is among the mid-century tall buildings in need of façade retrofit. (Mic Patterson)
图1. 西尔斯大厦（又称威利斯大厦），于1974年建成，是一众20世纪中叶高层建筑需要进行外墙翻新改进的大厦之一

The Problem with Buildings

There is an increasing awareness of the challenges presented by the built environment. The energy problem presented by the existing building stock is now well documented; in the US, the building stock is attributed with consuming upwards of half of all energy–as much as the transportation and industrial sectors combined–and is responsible for nearly the same percentage of carbon emissions. In addition, buildings are responsible for over 75% of electricity consumption. This is especially concerning in the many regions where coal is the dominant fuel source for electricity generation.

The problem posed by buildings is clearly significant. Various initiatives like the 2030 Challenge (Architecture 2030, 2011) and the LEED (Leadership in Energy and Environmental Design) program have brought a lot of critical attention to this problem (USGBC 2011). Still, the problem is grand in scale and there is much to be done. The early focus, as represented by LEED, has been on new buildings. The US Green Building Council, which administers the LEED program, instituted in 2007 the EB:O&M (Existing Buildings: Operations & Maintenance) program in recognition of the problem presented by existing buildings. The 2030 Challenge includes consideration of existing buildings (Architecture 2030, 2011a).

In New York City, where energy use in buildings is responsible for 75% of the city's carbon emissions, planners estimate that approximately 85% of the city's existing buildings will still be standing in 2030 (PlaNYC, 2011, p. 204). What percentage this will represent of the total building stock in 2030 depends on an uncertain future of construction, but clearly, they will be a determining factor in the overall energy efficiency of the city's building stock. Consequently, goals for future reductions in energy consumption and related carbon emissions must be built on a foundation of improvements to the existing building stock.

同时也有其缺点。当时来说，这种技术是全新的。材料供应商、制造者和安装者对这种新的建筑形式缺乏经验（Prudon 2008），同时这种外墙系统的需求小。在那时城市环境大部分是由包含办公楼的商业中心组成的，上班族白天聚集到城市上班，晚上回到他们郊区的住所。由一些如隔音与隔热性能等衡量方法所表示的舒适性则更少获得关注（Fitch & Bobenhausen 1999）。大部分的早期高层建筑外墙均是安装的单层玻璃。空气渗入甚至雨水渗透都是很普遍的问题。

简而言之，早期高层建筑上的幕墙系统在开始时没有良好的性能表现，而且有一些已经使用了近40年或更久。它们中很大的一部分已不能满足现时建筑标准的要求，有一些甚至可能会在面对由气候变化引起的频繁暴风活动中存在安全隐患。很明显，这些较旧的高层幕墙建筑在外墙翻新改进方面具有很大潜在的必要性（图1）

建筑上的问题

意识到建筑环境所带来的挑战有增加的趋势。现有建筑的能耗问题如今是有据可查的。在美国，建筑的能耗量占了总能耗量的接近一半，相当于交通和工业领域的总和，并且建筑的二氧化碳排放量也近乎占了同等百分比。此外，建筑消耗了超过75%的电耗。在许多以煤为主要发电能源的地区，这个问题尤其忧虑。

建筑表现出来的能耗问题是非常重要的。各种倡议项目如2030挑战计划（Architecture 2030, 2011）和LEED（能耗和环境设计指导）都对这个问题提出许多评论关注（USGBC 2011）。这个问题所涉及的范围仍然很大，而且还有许多事要去做。早期的关注点，如在LEED中，都是集中在新建建筑中。管理LEED项目的美国绿色建筑委员会在2007年建立了EB:O&M项目（现有建筑：运作和管理）来认识现有建筑中存在的问题。2030挑战计划包括了对现有建筑的考虑（Architecture 2030, 2011a）。

在纽约市，建筑能耗占了整个城市碳排放量的75%，规划师

In the US domestic market the yearly unit area of new building construction is roughly equaled by building renovation. In a down market cycle, the relative percentage of renovation work can be expected to increase. The volume of new building construction combined with existing building demolition and renovation has the potential to transform the built environment in the relative short term. The 2030 Challenge projects that 75% of the built environment will be new or renovated by the year 2035. It is estimated that renovation of existing stock is related to 86% of the U.S. annual building construction expenditure (Landsberg et al. 2009). It is a problem however, that most of these renovations tend towards the cosmetic, and even the energy retrofits fall short of optimal results.

Rethinking the Building Energy Retrofit

The pace of building sector transformation can be most effectively accelerated by increasing the occurrence and efficacy of building renovations. Building code policy, financial incentives, and emergent energy efficient technology and design techniques that impact the pace of building renovation are the key to fueling this market transformation. This is not a matter of simply picking the low hanging fruit; most building energy retrofits address upgrades to lighting and mechanical systems and stop there. Many buildings will require a more aggressive intervention to transform energy performance in a manner that can build towards a sustainable building stock. Deep renovations are often called for, comprehensive interventions that integrate system performance for optimal results.

The existing building stock is comprised of many different building types, and energy retrofit practices will certainly need to be tuned to some categorization of building type. Tall buildings are unique in many respects. From the 1960s onward, tall building facades are dominated by curtain wall systems, often featuring large areas of glass. As exterior wall systems, curtain walls mediate between the inside and outside environment, and are integral to building energy performance and comfort. Despite this, the façade systems are often excluded from building energy retrofits. The reasons are cost and the potential for disruption to ongoing building operations.

These are lost opportunities. Optimal performance is attained through systems integration and energy modeling, which allows all of the systems to be tuned to the application. If the mechanical systems, for example, are upgraded independently they must be designed to compensate for the inefficiencies of the original façade, and the opportunity for optimization is lost. Fast-forward a few years and increasingly aggressive code requirements may well mandate replacement of the old façade, resulting in the mechanical systems being oversized for the application. Conditions of economic stress and material scarcity may limit the options for repeated iterations of retrofit going forward. It is important that the upcoming retrofits are accomplished as efficiently as possible, and are optimized for long-term durability and performance.

Tall Challenges

There are issues that challenge the sustainability of tall buildings, effects that must be mitigated so as not to compromise the benefits provided by this building type. Not surprisingly, these issues are a function of building height. The goal of a low carbon building sector is to minimize the life cycle impact of the building. The façade systems are a necessary contributor to this achievement.

估计到2030年大约有85%的现有城市建筑仍将继续被使用（PlaNYC，2011，p.204）。在2030年这些建筑在总建筑存量中所占比重取决于未确定的未来建设，但很清楚的是，它们将会在总城市建筑存量的能耗中起到决定性因素。因此，要在未来实现减少能耗和相关的碳排放量的目标，必须在改善现有建筑物的基础上建立。

美国本土市场每年新建建筑的建筑面积大约与建筑整修面积相等。在低迷的市场下，建筑整修作业所占的相对百分比可如预计增加。新建建筑结合着现有建筑的拆除和整修的数量在相对短期内有着可以改变建成环境的潜力。在2030挑战项目中，到2035年75%的建成环境将会是新的或是整修过的。据估计，对现有建筑存量的整修会是相对美国全年建设开支的86%（Landsberg et al. 2009）。然而问题是建筑整修中的大多数都是倾向于表面装修，即使是节能改进也达不到最佳效果。

反思建筑节能改进

提高建筑整修数量和功效可有效地促进建筑行业转型的步伐。影响建筑整修步伐的建筑规范政策，财政奖励，新兴的高效能源技术和设计技巧是这个市场转型的关键。这不是一个简单地挑选低挂水果的问题；大部分的建筑节能改进只对灯和机械设备系统进行升级，并到此为止。许多建筑则需要更积极的介入以改变节能性能，使其向着可持续建筑的方向发展。深度整修往往是有必要的，通过对合整系统性能的全面干预来达到最佳效果。

现有建筑存系许多不同建筑类型的组合，节能改进的方法也要根据不同的建筑形式而有所调整。高层建筑在很多方面是独特的。从上世纪六十年代之后，高层建筑的外墙均以幕墙系统为主导，通常以大面积的玻璃为特点。作为外墙系统，幕墙联系着内部和外部环境，与建筑能源绩效和舒适度是一体的。尽管如此，外墙系统经常会因高昂的费用和中断建筑物持续营运的可能而不被包括在建筑节能改进中。

这些都是失去了的机会。最佳性能是要通过运用系统整合和能源模拟，以允许所有系统安照相关应用作出调节。例如，如果机械 设备系统独立地升级，那么系统设计必须要弥补原外墙的低效，同时还错失了优化的机会。向后推进一些年，越来越多严格的建筑规范要求可能会授权要求替换旧外墙，这使机械设备系统在 对相关应用中出现负荷设计过大的现象。经济上的压力和材料缺乏的条件可能让反复进行的改进循环有所受限。使将要进行的改进尽可能高效地完成并优化其长期的耐用性与性能是非常重要的。

高度上的挑战

有很多问题会挑战到高层建筑的可持续发展，必须减缓这些影响，以免危及这种建筑形式带来的优势。这些问题源于建筑高度，这并不意外。低碳建筑的目标是使建筑生命周期的影响减至最少。外墙系统是实现这个目标的一个必要贡献者。

生命周期评价（LCA）和包含LCA的成本策略在评价一种材料、产品、建筑或城市成本的真实影响中成为日益重要的评价工具。除了在建筑整个服务周期内的营运能耗，自含能耗也是LCA的一个重要组成部分。对于任何材料或产品，除了制作中的预期能耗外，LCA包括了原材料提取、加工及运输。除此之外，作为建筑项目的一部分，还有在建设施工、材料到工地的运输、在工地上对材料的再加工和安装过程中的能耗（Sorensen 2011）。这些总和加入到建筑本身的自含能耗中，包含所有材料和产品自含能耗的总和、工人来往工地的能源消耗、在加工和安装活动中所有设备消耗的能源和材料。

Life cycle assessment (LCA), and costing strategies that embody LCA, are increasingly important tools in evaluating the true impact and cost of a material, product, building, or city. In addition to operating energy over the service life of a building, embodied energy is an important component of LCA. For any given material or product, LCA includes the energy consumption involved in raw material extraction, processing, and transport, in addition to the energy expended in manufacturing. Added to this as part of a building program is the energy consumed during construction, in transport of the material to the site, in any further onsite processing of the material, and during installation (Sorensen 2011). This total is added to the embodied energy of the building itself, which includes the sum of the embodied energy of all materials and products, the energy consumed by workers commuting to and from the site, and the energy and materials consumed by all equipment during assembly and installation activities.

Getting the materials and workers up to the higher elevations of a tall building adds to the embodied energy of the building, just as the continuous requirement to move building occupants up and down the building adds to the operational energy consumption over the lifetime of the building. Unitized curtain wall technology has developed in response to the need to minimize site labor, and is consequently effective in minimizing energy consumption during the installation process.

Extended lifespan and speed of construction of a system are two factors that balance the impact of embodied energy. Early mid-century curtain wall technology has evolved to the prefabricated, modular systems of today, referred to as unitized curtain wall systems. They are designed to be factory assembled into large modules called units (see Figure 2). The object is to minimize site labor, which at least in some regions comes at high cost. In addition, the building site presents a host of conditions adverse to the quality craftsmanship required for optimum facade system performance. Factory assembly promotes quality while reducing the cost of expensive site labor, thereby improving durability while accelerating the installation process (see Figure 3). Improved quality also reduces energy consumption from building operations over the lifetime of the façade.

Unitized curtain wall systems once installed, however, can be exceptionally difficult to access and maintain, especially in tall building applications. Assumptions regarding façade maintenance over the service life of the curtain wall system are usually minimal, and typically make provision only for periodic cleaning. Even this comes at considerable expense; exterior window-washing systems for tall buildings can be quite sophisticated and costly. While these systems may be effective for localized repair work, they are generally ineffective when it comes to system-wide renovation.

A Failure to Anticipate

Consider again the tall building. There is an apparent mismatch in building design, at least when it comes to two primary building systems; the structure and the façade. The structural system is a steel or steel and concrete construct typically protected from the exterior environment. Tall buildings are a fairly new building type, first appearing in the late nineteenth century. Of the 19 projects included in the tall building database of the Council for Tall Buildings and Urban Habitat (CTBUH 2012) that were constructed in the US before 1900, only four have been demolished. Of the 124 built by 1920, only 17 have been demolished. In other words, 86% of the high-rise buildings built by 1920 are still standing ninety-two years later. It seems a reasonable premise that building structural systems should have a lifespan of 100

Figure 2. Curtain wall units in production at an assembly plant where quality can be better controlled than on the building site. (Enclos Corp)
图2. 相比在建筑工地，幕墙单元在组装工厂内生产有更好的质量控制。（Enclos Corp）

把材料和工人运送到高楼的较高楼层增加了建筑的自含能耗，就如同运送建筑内用户上下的需求增加了建筑整个生命周期中的营运能耗。单元式幕墙技术的发展是为适应最小化工地人力的需求，从而有效地在安装过程中使能量消耗最小化。

系统的使用期限延长与施工的速度是平衡自含能耗影响的两个因素。上世纪中早期的幕墙技术已经发展到今天的预制模块系统，称为单元式幕墙系统。它们被设计于工厂中组装成大型模块，即单元（图2）。这样做的目的是为了尽量减少工地劳动，至少在一些地区工地劳动的成本是很高的。此外，在建筑工地内有许多条件不利于最佳外墙系统性能所需要的高品质工艺要求。工厂组装在改进质量的同时，减少了昂贵的工地劳动成本，因此增强其耐久性，也加快安装进程（图3）。质量的提高也减低在外墙使用期限内的建筑营运能耗。

单元式幕墙系统一旦安装好，维修维护就会异常困难，特别是在高层建筑的应用中。预计在幕墙系统有效期限内的外墙维护普遍来说是极少，一般只规定做定期性的清洁。清洁是一笔相当大的开支；高层建筑的外窗清洗系统可以是繁复和昂贵的。尽管这些系统可能对局部维修工作有效，但在整个系统整修情况下，通常是无效的。

Figure 3. The prefabricated modules of a unitized façade system speed the erection process. (Enclos Corp)
图3. 单元式外墙系统的预制模块加快了安装速度。（Enclos Corp）

years (and will likely survive considerably beyond that, especially with the increasing focus on preservation and reuse, but 100 years is ample to make the argument pursued herein).

The façade systems are a different story. The facades of most buildings prior to the mid-twentieth century were of masonry perforated with windows. This technique was gradually replaced in tall buildings around mid-century with the early curtain wall systems, the precursors to today's unitized technology. The performance of these masonry facades is not a useful indicator of the durability of the newer curtain wall systems, comprised as they are of different materials. Curtain wall systems are built predominantly of aluminum framing with glass and metal panel infill. Façade systems, unlike structural systems, have significant exposure to climatic conditions, directly impacting the durability of exposed seals and finishes. In addition, the service life of the materials and components used in the façade systems generally fall well short of the 100-year mark. Insulated glass units (IGUs), for example, a ubiquitous component of today's façade systems, are typically warrantied for 5 to 10 years with an expected service life of 20 and 30 years. A lifespan design target for IGUs in the building façade might be 30 years at the outside, and degradation to both appearance and performance are common before then (see Figure 4). This implies the necessity for repair or, more probably, the replacement of the IGUs at least three times during the building life cycle.

Architectural glass is also a very dynamic material, with industry providing frequent improvements to performance. The glass of today performs significantly better than the glass of thirty years ago. Even if more durable IGUs are developed, there may be a compelling reason for cyclical retrofit as an opportunity to improve performance.

Each intervention in the facade will add to the embodied energy account of the building (as well as subtract from the owners bank account). It would seem logical to plan for this, to design the façade system to accommodate the inevitability of future retrofit requirements. Yet this is not the case at all.

Contemporary curtain wall systems are not designed to be maintained, repaired, refit, or renovated beyond periodic cleaning. Curtain wall systems for tall building applications are typically custom-designed to specific building requirements, but without any consideration to future retrofit needs. Units are factory assembled without regard to how they might be disassembled in place to facilitate a panel upgrade, for example, as with the installation of a higher performance glass. Glass is often structurally glazed (glued) to a framing member, and in-situ access to the silicone bond can be nearly impossible. Simply the ability to easily change out glass panels could present a significant advantage for future retrofit activities. In addition, the curtain wall units are set in sequence and interlock with adjacent units in a manner that makes the removal of a single unit quite difficult.

Rethinking Curtainwall System Design

The construction of tall buildings has entered a dramatic boom period In spite of ongoing predictions of the imminent demise of the skyscraper, and ongoing arguments over the sustainability of the building type. The geographical regions of construction activity have shifted, however, predominantly to Asia. The Council for Tall Buildings and Urban Habitat (CTBUH) reports that 2010 was a banner year for the skyscraper, with more buildings over 200 meters completed during this year than any previous year in history (CTBUH 2011). They also got taller; 8 of the 66 skyscrapers completed in 2010 were supertalls (over 300 m), another record for the year, and included 4 over 400

预期不足

再次考虑高层建筑。在建筑设计有一个明显的区别，至少在涉及两种主要的建筑系统；结构和外墙。结构系统是钢构或钢与混凝土建造，一般被保护免受外界环境影响。高层建筑是一种较为新兴的建筑形式，其最开始出现是在十九世纪后期。世界高层都市建筑学会（CTBUH 2012）的高层建筑数据库中有19个项目是1900年前在美国建造的，其中只有4个已被拆除。在到1920年为止建造的124座高层建筑中，只有17座已经被拆除。换言之，1920年之前所建造的高层建筑，当中的86%已屹立了92年之久。由此可以做出合理的假设，建筑结构系统应该可以有100年的寿命（很可能会更长，特别是随着对保护和再利用的日益关注，但在这里100年已足够支持所提出的论点）。

外墙系统是很不同的。在20世纪中叶之前，大部分建筑的外墙是石砌带窗户留洞的。这种技术在20世纪中叶左右的高层建筑中逐渐被早期的幕墙系统所取代，是现在的单元式技术的前身。石砌外墙的性能对于更新的幕墙系统的耐久性来讲并不是一个有用的评价指标，因为它们是由不同的材料组成的。幕墙系统主要是由铝合金框结合着玻璃和金属面板填入组成。不像结构系统，幕墙系统很大部分暴露在气候条件中，直接影响着外露密封和饰面的可耐久性。此外，外墙系统中材料和构件的有效寿命一般较100年的期限更短。例如，中空玻璃单元（IGUs），一个在当今外墙系统中随处可见的部件，其预计有效寿命为20到30年，普遍的保修期为5到10年。建筑外墙中的中空玻璃设计有效期限充其量可能是30年，但通常在那之前外观和性能就已退化（图4）。这意味着在建筑的寿命周期中对中空玻璃单元的必要性维修或更可能的替换至少有3次。

建筑玻璃是一种非常动态的材料，因业界会经常改进玻璃的性能。现在玻璃的性能远好于30年前的玻璃。即使开发出了更耐用的中空玻璃单元，还是可能有一个使人信服的理由来改进周期性成为提高性能的机会。

每一次在外墙上的干预都会增加整栋建筑的自含能耗（也同时从业主的银行账户内扣除一定数额）。设计一种外墙系统来适应未来翻新改进的必然性，这种计划表面看似合理。但是现实根本不是这样。

现代幕墙系统在设计时除了周期性的清洁外，并未考虑维护、维修、重新装配或整修。幕墙系统在高层建筑应用上一般是针对建筑需求特别设计的，并没有考虑未来的翻新改进需求。单元在工厂中组装，并没有考虑如何在固定位置拆卸使板块升级容易，比如说要安装一种更好性能的玻璃。玻璃经常是结构性的装（粘）在框架构件中，要在现场靠近硅胶黏合几乎是不可能的。简单地容许玻璃板块轻易的替换就可以使未来翻新改进中表现出巨大的

Figure 4. IGUs in place since the mid 1980s are currently being replaced at the Javits Convention Center in New York City (new units to the right). (Enclos Corp)
图4. 纽约市Javits 会议中心在上世纪80年代安置的中空玻璃单元现在正在被替换中（右边为新单元）。（Enclos Corp）

m comprising the 1st, 4th, 7th and 9th tallest buildings in the world, surpassing the 600, 700, and 800 m thresholds in this singular year.

Developing markets will soon enough become developed markets. The construction community must recognize the inevitable need, and plan for the future façade retrofit of new tall buildings. Markets now experiencing a tall building boom have the opportunity to build better performing and longer lasting buildings that anticipate and accommodate the need for future façade retrofit.

Two important predictions regarding these newer tall buildings can be made with some certainty:

- They will be around for many decades; and
- They will require renovation to the building façade during the lifetime of the building.

The following generalized design guidelines for curtain wall systems in new building applications can improve the durability, adaptability, and implementation of future curtain wall retrofits, potentially reducing building life-cycle cost:

- Establish a life-cycle target for the curtain wall system that matches the target for the building lifespan.
- Assess the durability of all curtain wall components with respect to their exposure to the elements within the system: metals, fasteners, finishes, sealants, and gaskets.
- Identify operable systems and components in the curtain wall and assess their wear and durability based on projected usage.
- Isolate materials and finishes exposed to the elements and design them for extended durability.
- Anticipate the potential for future higher-performing materials and adaptive reuse requirements.
- Design framing systems and anchorages to be as durable as possible, ideally requiring only minimal maintenance for the target life cycle.
- Make panel materials easy to change-out from the inside or outside of the building, depending upon retrofit installation strategy. To facilitate this, consider the development of a cassette-type system that eliminates the need to structurally glaze glass panels to the primary framing system.
- Make provision for accommodating inspection and replacement of the weather seals of the system.
- Combine these anticipated requirements with the durability data to establish a maintenance/replacement program and accompanying means-and-methods implementation strategy that supports the target life cycle. This can then be used to facilitate life cycle costing analysis and the comparison of design alternatives.

Summary

While the above guidelines are logical, industry professionals will immediately recognize that they are not easily applied. Nor are they readily adopted. The metrics of sustainability for tall buildings is a matter of ongoing debate. Façade retrofit is an important part of this dialog. There are no easy solutions to the challenges of sustainability in the built environment. Yet this is the task at hand. A sustainable future lies in the application of anticipatory design science.

优势。此外，幕墙单元是按顺序设置并与毗邻单元连锁使得拆卸单一单元较为困难。

反思幕墙系统设计

尽管不断预测摩天大楼的灭亡即将发生，以及针对这种建筑形式可持续发展性的争论，但高层建筑的建设也进入过给人深刻印象的繁荣时期。建设活动的地理区域已经转换了，主要地都在亚洲。世界高层都市建筑学会（CTBUH）报告称2010年是摩天大楼建设的标志性一年，在这一年超过200米高的大楼建成，数量超过了历史上的任何一年（CTBUH 2011）。这些大楼也越来越高，2010年建成的66座摩天大楼中有8座是超高楼（超过300米），是这一年的又另一项纪录，这包括4座超过400米高的楼分别占据了世界第一、第四、第七和第九高楼， 且这一年里超越了600、700和800米的界限。

发展中的市场将很快变成成熟的市场。建设团体市场必须意识到这种必然的需求，为今后新高层建筑的外墙翻新改进做准备。市场正在经历一场高层建筑的浪潮，有机会去建造更好性能且更持久的建筑，可以预期和适应未来外墙翻新改进的需求。

对于这些新建高层建筑有两点重要的预测是比较确定的：

- 它们将屹立几十年；同时
- 在建筑的寿命周期内，建筑外墙将需要整修。

以下对幕墙系统在新建建筑应用中列出了一些一般性的设计指引，可以改善未来幕墙翻新改进工作的耐久性、适应性和履行性，可潜在地减少建筑寿命周期的成本：

- 建立幕墙系统的寿命周期目标，并与建筑周期的目标相配。
- 评估所有幕墙构件的耐久性，考虑它们与系统中元件的接触：金属，紧固件，饰面，密封胶和垫片。
- 区分幕墙的可操作系统和组件，根据其预计的使用功能评估它们的磨损和耐久性。
- 将材料和接触系统元件的饰面分隔，延长其耐久性的设计。
- 对未来潜在的更高性能的材料和自适应重用的要求作出预计。
- 设计框架系统和锚固件，使之尽可能的耐久，观念上在目标寿命周期中只需要最小程度上的维修。
- 使面板材料可以轻易的替换，不管从建筑内部还是建筑外部进行，这取决于翻新改进安装策略。为方便这一点，考虑发展卡机式系统以取消结构性装玻璃板块置主框架系统的必要。
- 为顾及系统耐候密封的检查与替换提前做好相应措施。
- 结合这些预期的要求与耐用性数据来建立一个维护/替换机制，并补充可支援目标寿命周期的手段和方法执行策略。这种机制有助寿命周期的成本分析和设计备选方案的比较。

总结

尽管上述指引是有逻辑性的，但业内专业人士会马上意识到这些是不容易实施或欣然接受的。高层建筑可持续性的衡量标准是一个热论中的话题。外墙的翻新改进是这个话题中一个重要的部分。对于建成环境可持续性的挑战没有一个简单的解决措施的。但这始终是一项手头上的任务。可持续发展的未来在于预期设计技术的运用。

Conclusions

- There is a massive looming need for the façade retrofit of tall buildings constructed in the mid twentieth century and onward. This process is costly and complex, with high potential for waste and inefficiency. These retrofits must be done in a manner to optimize life cycle material and energy consumption and minimize environmental impact.
- The durability of materials and systems requires priority consideration early in the design process. The service life of all materials, products, and system components must be identified and matched to the targeted lifespan. The durability of materials and systems should be extended as a fundamental sustainability strategy.
- Current design practices do not anticipate the need for retrofit. Facade systems can be better designed to accommodate retrofit and adaptive reuse.
- Newly developing markets for the application of tall buildings hold the potential to develop more sustainable building practices by designing to facilitate future façade retrofit requirements.

结语

- 有大量的外墙翻新改进需求出现在20世纪中叶及之后建造的高层建筑上。这个过程是昂贵且复杂的，并存在浪费和低效的高风险。这些翻新改进必须以优化寿命周期材料和能量消耗及尽量减少对环境的影响的方式完成。
- 对材料和系统的耐用性需要在设计阶段早期就优先考虑。所有材料、产品和系统构件的使用寿命一定要明确并与目标寿命期限相匹配。作为一项基本的可持续策略，材料和系统的耐用性应可延长。
- 现有的设计习惯并没有预计到翻新改进的需求。应该更好地设计外立面系统以适应翻新改进和适应性重用。
- 高层建筑的应用在新兴市场掌握着未来外墙翻新改进的需求融入到设计中，会更具有发展可持续建筑的潜力。

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