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Tencent Seafront Tower – A Case Study on Façade Engineering as Functional Patterns | 腾讯滨海大厦——幕墙工程设计与功能法式

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CK Dickson Wong completed his masters in Architecture at the Massachusetts Institute of Technology, and has worked at industry-leading architectural firms, including Foster and Partners in London and Rocco Design Architects Limited in Hong Kong. Leveraging a robust knowledge of computational and parametric tools, he spearheaded computational design initiatives and developed unconventional façade solutions for a number of high-profile projects in the region. As a façade consultant and registered architect, Wong has extensive experience with the design and construction management of numerous high-rise buildings in South China region.

CK Dickson Wong 是一名注册建筑师，现于英海特任职高级幕墙顾问。他在美国麻省理工学院完成了建筑学硕士学位（M.Arch)后先后在多家领导业界的建筑师事务所工作，其中包括伦敦的 Foster and Partners及香港的许李严建筑师事务所。 凭借对计算性及参数化设计工具的知识，他开展了英海特计算性设计的先驱性工作，并完成了区内多个高端项目开发的非传统的外墙方案。作为一名幕墙顾问，他拥有多年丰富的中国华南地区高层建筑设计及施工管理经验。

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Hugh Brennand is responsible for the business operations of the Hong Kong and Macau offices. He oversees projects in China and South East Asia, provides technical support and mentoring to the Inhabit team, and manages the firm's Hong Kong office. With expertise across a range of project types, Brennand has developed design knowledge that covers a vast array of façade systems and materials, as well as complex geometry resolutions, access and maintenance and, more recently, lighting and ESD disciplines, all of which have a direct integration with the façade.

Hugh Brennand 并负责经营英海特在香港及澳门办公室的业务。他负责管理英海特香港办公室的工作，并监督中国及东南亚的项目，以及为英海特的团队提供指导及技术支援。 凭借多种项目领域经验，Hugh发展了不同领域和种类的幕墙系统及材料的设计知识。他的专业强项包括复杂几何方案，擦窗机及建筑维护系统，幕墙灯光设计及绿色建筑设计。

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Vincent Ng has over 10 years of experience in drafting and designing curtain wall façades. He is responsible for designing different types of façade and building maintenance systems, and handling statutory submissions for curtain wall systems, reinforced concrete structures, steel structures and A&A works. Ng also holds experience in building 3-D models for façade design and building geometry studies. His expertise focuses primarily on projects in the Asia region, the majority of which are tall buildings. Ng has a thorough understanding and keen knowledge of super high-rise façades and BMU design, building standards, and construction.

Vincent 拥有超过10年的幕墙设计经验。他主要负责设计不同种类的幕墙系统及擦窗机系统，并负责处理针对幕墙系统的法定图则的工作。他的项目经验包括混凝土结构，钢结构以及改建与加建项目。对于应用于幕墙的建筑三维模型技术及建筑几何研究也颇具经验。Vincent 的项目经验主要在亚洲，以高层建筑为主。他对超高层建筑的外墙设计，维护系统，建筑规范及施工有透彻的了解。

Abstract | 摘要

A methodology that façade engineers commonly use to understand and detail a façade element is to break it down into "functional patterns" – principles that are analogically applied where certain relationships between tectonic elements are identified – thus allowing façade engineers to logically deduce solutions that are specific to the geometry and structural conditions of the façade element that is being dealt with. This paper takes the Tencent Seafront Towers as an example to study how the façade engineers creatively interpret the tectonic relationships of different façade elements in a geometrically complex façade system, and apply functional patterns to a geometrically complex façade in order to ensure that both the performance and aesthetic requirements of the façade systems are fulfilled.

Keywords: Construction technology, Design Process, Façade, Prefabrication, Systems, Technology

幕墙工程师尝试理解及设计幕墙元件的细部时，常将该元件化解成一系列的“功能法式”。 “功能法式”可理解成当构造元件之间需达致某种关系时一些可以类比的方式应用的技术原则。幕墙工程师可透过把元件的关系理解成种种的功能法式，有逻辑的推演出针对不同的幕墙几何及结构状况的解决方案。 此论文以腾讯滨海大厦为例，简述幕墙工程师如何于一个几何上复杂的幕墙系统上有创意的阐译不同幕墙元件之间的构造关系，如何应用功能法式于一个几何复杂的外墙系统上，以确保其功能及外形上均能满足要求。

关键词：施工技术、设计过程、幕墙、预制、系统、技术

Introduction

With the advent of computer numeric control (CNC) technologies in the façade industry and the development new digital design and automation tools that enable architects to create, understand and manipulate complex building forms, the architectural design and engineering community's ability to compose novel architectural expressions through the building's façade have reached new heights. Motivated by the designers' technical and aesthetic pursuits, the façade industry has been constantly reinventing itself, introducing technologies and tools from other fields to realize the designers' visions.

Although the complexity of façades has taken a great leap forward, the basic functions that are expected of a façade – to shelter the building users from the elements; to provide views where they are needed; to facilitate natural daylighting and ventilation within the building; to help provide thermal comfort and reduce the heating/cooling load of the building; and more – have not changed. If anything they have only become more important as façades are becoming more critical to a building's overall performance. These age-old functional requirements, combined with the increasingly

简介

随着幕墙工业所使用的数控技术不断进步，以及建筑师开始使用容许他们创造、理解以及调度复杂的建筑形体的自动化科技，建筑设计及工程专业以建筑幕墙来营造日新月异的建筑形态的技术达到了前无古人的水平。幕墙工业也因为设计师对技术和美感的追求而不断地重塑本身的技术，并引进了其他专业的科技和工具来实现设计师的想象。

虽然幕墙变得比以前复杂，用家对其基本功能上的要求 – 如为建筑物的用家提供遮盖、 在有需要的地方引进室外的景观、把自然光和新鲜空气带进室内、保持室内温度适中、帮助提高建筑物在温度调控的效能等 – 并没有太大的改变，甚至有所提升。这些历久不变的功能要求加上越来越复杂的建筑形态大大提高了幕墙工程的技术挑战性。

幕墙工程师尝试理解及设计幕墙元件的细部时，常将该元件化解成一系列的“功能法式”。功能法式可理解成当构造元件之间需达致某种关系时一些可以类比的方式应用的技术原则。慕墙工程师可透过把元件的关系理解成种种的功能法式，有逻辑的推演出针对不同的幕墙几何及结构状况的解决方案。Allen 对此思考方式总括

Figure 1. Rendering of the Tencent Seafront Tower (Source: NBBJ)
图1. 腾讯滨海大厦效果图（来源：NBBJ）

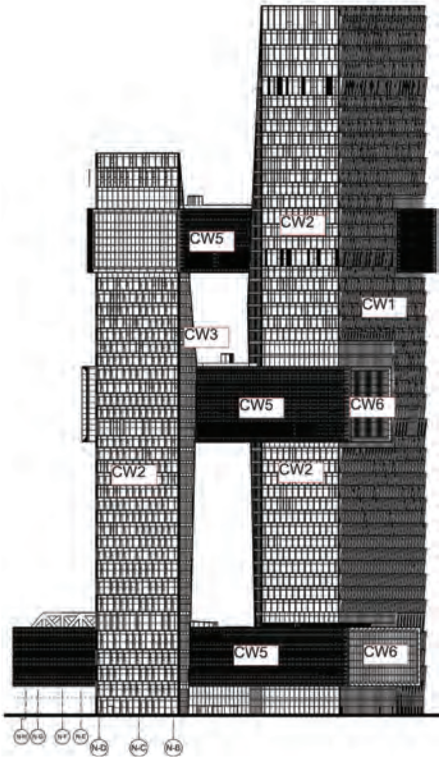

Figure 2. Location of various façade systems in the building (Source: NBBJ)
图2. 不同幕墙的位置（来源：NBBJ）

complex forms envisaged by the designers, have posed great technical challenges to façade engineers in recent years.

A methodology that façade engineers commonly use to understand and detail a façade element is to break it down into "functional patterns" – principles that are analogically applied where certain relationships between tectonic elements are identified – thus allowing façade engineers to logically deduce solutions that are specific to the geometry and structural conditions of the façade element that is being dealt with. This methodology is perhaps best summed up by Allen: "Each detail, no matter how special or unprecedented, is designed in conformance with universal, timeless patterns that, given competent execution on the construction site, virtually guarantee satisfactory building performance" (Allen, 1993).

This paper takes the Tencent Seafront Towers as an example to study how the façade engineers creatively interpret the tectonic relationships of different façade elements in a geometrically complex façade system, and apply functional patterns to a geometrically complex façade in order to ensure that both the performance and aesthetic requirements of the façade systems are fulfilled.

Background

The Tencent Seafront Towers (Figure 1) make up the new corporate campus of Tencent – a Chinese internet and technology firm. Located in the Nanshan District of Shenzhen, the campus is consisted of two office towers (of 245.78 meters and 194.75 meters tall, respectively), connected together at multiple levels by "links" dubbed the "Culture Link" (located at the third to fifth floors), "Health Link" (at the 21st to 25th floors), and the "Knowledge Link" (at the 34th to 37th floors), in which public functions such as theatres, gyms, and libraries are introduced, respectively.

The building's façade consists of the following major system types (Figure 2):

- CW1 is located on the southern elevation; CW2 is on the northern, eastern, and western elevations; and CW3 is on the façades of which the two towers face one another. These three systems, all of which are unitized systems, cover up to 80 percent of the façade area of the buildings.
- On the three "links," there is CW5 – a unitized system with bronze-colored extruded aluminum sun-shading grille pre-installed on the units under factory conditions.
- At the ends of each link, there is CW6 – a glass wall system with glass panels supported by custom-made, galvanized steel armatures that are in turn supported by tension rods and steel posts at the back.

如下：“每个细部，无论有多特别和史无前例，都可以按照一些永恒通用的功能法式设计。在建造工作执行有力的情况下，按功能法式设计的细部基本上可以确保建筑物能达到令人满意的功能”（Allen，1993）。

此论文以腾讯滨海大厦为例，简述幕墙工程师如何於一个几何上复杂的幕墙系统上有创意的阐译不同幕墙元件之间的构造关系，如何应用功能法式令幕墙系统功能卓越、外形美观。

背景

腾讯滨海大厦（图1）是腾讯公司 – 中国的一家互联网及可以公司 – 位于深圳南山区的新商业总部。大厦包括两栋办公塔楼 （分别高 245.78m 及 194.75）。两栋塔楼之间以名叫‘文化连接’(3–5F)、健康连接（21–25F）及‘知识连接’(34–37F）的多层‘连接’ 互相联系。每个连接里有不同的公共功能，分别包括剧院、健身房及图书馆等。

大厦的外墙系统包括以下几类（图2）：

– 位于南立面的CW1；位于北、东、西立面的CW2和位于两栋塔楼相对位置的 CW3。三个系统均为单元式幕墙系统，覆盖达整栋大厦的 80% 外墙面积。

– 位于‘连接’上的CW5；此系统为单元式，配有预先安装在单元件上的古铜色铝型材遮阳格栅。

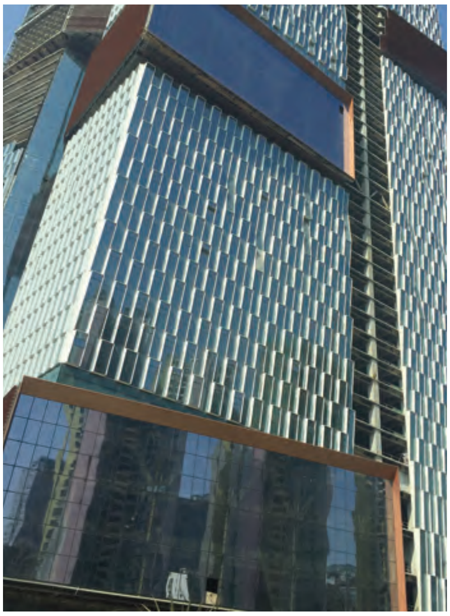

Figure 3. South façade of the south tower in progress (Source: CK Dickson Wong)
图3. 南塔南立面施工中照片（来源：CK Dickson Wong）

This paper primarily focuses on CW1 and CW2 to demonstrate the creative re-interpretation of established functional patterns to accommodate the complex geometry that the systems need to accommodate.

CW1

CW1 is a unitized system that is located on the approximately 95-meter-wide southern facing elevation, looking towards Bin Hai Road – the major artery of the area. Visible from multiple strategic vantage points of the city, this elevation is composed of approximately 17,130 square meters of glass panels installed on pre-fabricated façade units. These glass panels incline upwards and downwards at seemingly random angles, aggregating to form a pattern that moves and shimmers in a subtle rhythm under the sun (Figure 3).

Ever since the start of the design process, the architect had been aware of the need to standardize the degree of inclination of the façade units to achieve maximum repetition and to facilitate pre-fabrication of façade units under factory conditions, without sacrificing the sense of randomness that characterizes the elevation's composition. A system of three pairs of module types with clear geometric definitions was therefore introduced as the "kernel" of the design. These standardized modules were further combined into a manageable number of combinations that repeat across the entire façade (Figure 4).

To achieve the desired inclination, and therefore the intended pattern on the elevation, each façade unit cantilevers outward from the support location on the slab edge at various distances up to 1,200 millimeters. Inside, these cantilevered façade units double as seating and even gathering spaces for the users of the office spaces. Furthermore, Shenzhen, which is located along the coast of Southern China, is susceptible to typhoons during summers. The façade systems are, given the height of the building, subject to an exceptionally high wind load.

From a façade engineer's point of view, these design conditions immediately point to a number of functional patterns that could be applied in combination with each other to achieve the required performance.

Pressure Equalization Chamber (PEC)

One of the most commonly cited functional patterns in the façade industry is the use of pressure equalization chambers – the use of a specially designed cavity in front of the air seal that equalizes the air pressure within the cavity with the exterior, and thus ceases air movement that drives water into the cavity.

In most unitized systems used in the South China region, each unit has a male and a female mullion that are interlocked with their opposites on the adjacent panels. The PEC between the male and female mullion is designed to achieve other functional patterns as well: to allow room for small lateral movements, thermal expansion, and fine adjustments during installation; to form a doubly-gasketed labyrinth that ensures air-tightness and prevents direct entry of moisture (Allen, 1993); and to form a continuous, axially released interlocking mechanism that transfers lateral loading

– 位于 ‘连接’尾端的 CW6；此系统为玻璃墙系统，系统上的玻璃板块由特制的镀锌钢钢爪固定。钢爪则由拉杆及钢柱支撑。

此论文透过集中讨论 CW1 及 CW2，展示出设计师如何重新演绎既定的功能法式，以配合建筑的复杂几何。

CW1

CW1 为单元式幕墙系统，位于大厦的南立面，面向繁忙的滨海大道，所以在深圳多处都可以看到。该立面由 17130 平方米的预制玻璃单元组成。每个单元上的玻璃板块都以看似随机的角度往上或往下倾斜。这些单元在立面上聚合，组成在太阳下闪闪发光的纹理（图3）。

设计阶段刚开始时，建筑师已意识到把幕墙单元倾斜角度标准化，以及重复同样单元在工厂单元组装层面上的重要性。但与此同时，建筑师亦不希望因为幕墙单元过度标准化而失去立面在观感上那种独特的随机性。因此，建筑师在设计时确立了三双模组种类作为设计的核心系统；每双模组都有精确的几何定义，并以简单的方式互相组合，以期板块能尽量重复，减低加工上的复杂性（图4）。

要达到设计所需的倾斜，以及立面上的纹理，每个单元都从楼板边沿的支撑点往外悬挑，悬挑的幅度可达到 1200mm 之多。在大厦内，这些悬挑的单元板块能提供座位甚至办公楼用家相聚活动的空间。此外，由于深圳市位于南中国沿海台风多发地区，加上大厦为超高层建筑，幕墙系统需要承受的风荷载可说是非常地高。

从幕墙工程师的角度来说，这些设计条件指向一系列可以复合应用在节点上的功能法式来达到所需的功能要求。

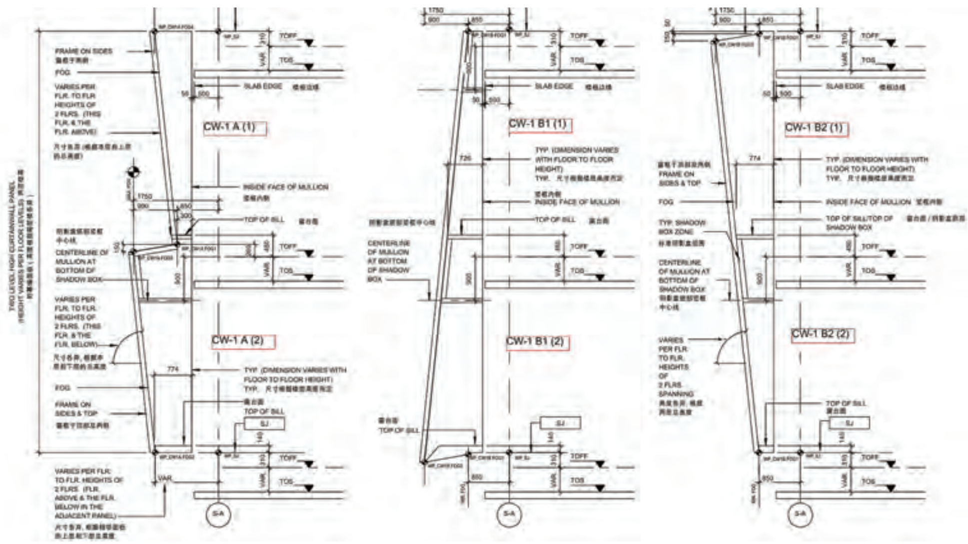

Figure 4. Standardized modules established by the designer during the design stage (Source: NBBJ)
图4. 设计师与设计初期建立的标准化模组（来源：NBBJ）

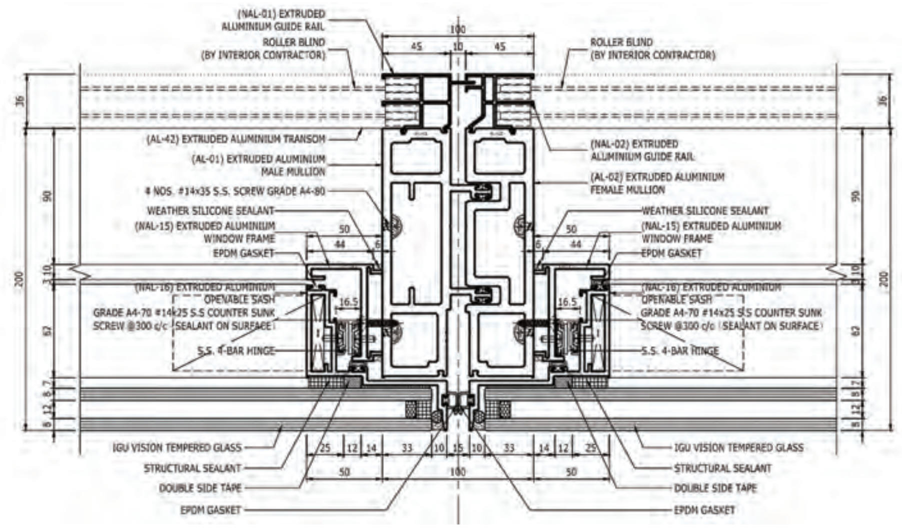

Figure 5. Conventional male and female interlocking mullion in a typical unitized system (Source: Inhabit Group)
图5. 传统单元式幕墙中的公母型材立柱紧扣节点（来源：Inhabit Group）

along the mullion to the unitized curtain wall brackets. Since these interlocked parts, by convention, perform both as part of the structural frame of the unit as well as barrier against uncontrolled water leakage between panels, the sizes and extrusion wall thickness of the male and female mullions are, under normal circumstances, dependent on the loadings they are subjected to. The use of interlocking mullions to perform both structurally and as the primary waterproofing line of the system work so well that it becomes an assumed norm for unitized system design (Figure 5).

In this case, however, the use conventional interlocking mullions as a structural and waterproofing element needed to be revisited. The sheer weight of the glass panels installed on the unit, the high wind load that the unit is subject to, as well as the distance at which the unit cantilevers from its support location would necessitate a strong moment connection on the male and female mullion, which would in turn induce enormous bending stress on the mullion as well as local stress at the connection. Should these interlocking mullion components be increased in depth and wall thicknesses, or be inserted with steel plate reinforcement to accommodate these stresses, the resulting extrusion may – in additional to becoming bulky and unsightly – necessitate the use of over-sized die, or cause frequent die damage during extrusion, and/or result in large extrusion waste due to defects caused by excessive closed chamber wall thicknesses. Although only manifested in millimeters, these decisions often have significant effects on the system's cost and buildability, owing to the highly repetitive nature of unitized systems.

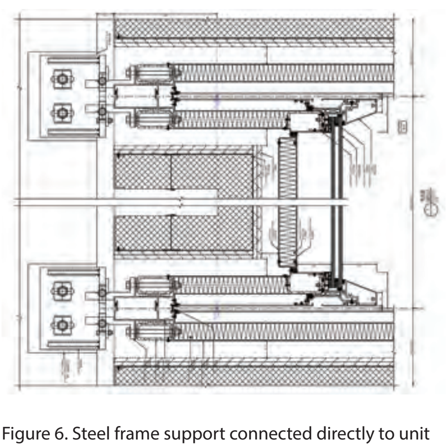

Figure 6. Steel frame support connected directly to unit brackets (male and female mullion extrusion for creation of PEC only) (Source: Inhabit Group)
图6. 刚性钢构架直接连接到单元的连接件。公母料只用于提供均压腔（来源：Inhabit Group）

Understanding a conventional mullion profile as a solution that combines multiple functional patterns is critical, as it allows façade engineers to creatively re-design and re-adjust components where required. In this case, where it is clearly uneconomical to use the interlocking male and female mullions as structural members to support the cantilevered units, it is nevertheless advantageous to keep the pressure equalization chamber for waterproofing purposes. The façade engineer therefore introduced, during the design stage, a rigid frame (Figure 6) connected directly to the unit brackets that supports the dead load of the glass panels and aluminum panel enclosure of the unit, and the wind loading to the façade panel. The male and female aluminum mullion extrusions, in this case, serve little structural purpose, but are rather are used to achieve functional patterns associated with waterproofing. Although the façade contractor eventually decided to use aluminum extrusions in lieu of steel members to form the supporting frame, this re-interpretation of functional patterns was adhered to during the construction stage.

均压腔

在幕墙工业里一个比较常见的功能法式是‘均压腔’– 在气密封堵线前方用特别设计的空腔来保持腔内的气压与室外气压一致，以防止空气因压差引致的流动把水带进腔内。

在南中国大多数的单元式幕墙系统里，每个单元都配备一条公立柱及一条母立柱。单元之间公立柱与母立柱紧扣一起。公立柱与母立柱之间的空腔除了作为均压腔外，还有其他功能 – 比如容许少量横向热变形、容许在安装单元后少量的调整；组成一个双胶条防水的 ‘迷宫’（Allen, 1993）以确保气密及防止水气进入（Allen, 1993），以及组成连续及在垂直方向释放的紧扣系统以把板块的横向荷载传递到板块的紧固件上。因为这些紧扣的部件传统上担当了单元结构框架的一部分及板块的防水线的作用，公母立柱型材和横梁的墙厚及尺寸在一般情况下需按照板块所承受的荷载设计。这种把公母立柱和横梁设计成防水线及提供板块的结构支撑的双功能设计在南中国区域十分适合，成为了该区域的单元幕墙设计的既定通用概念（图5）。

但在此项目的设计条件下，是否使用传统的多功能公母料设计就值得重新考虑。安装於单元上的玻璃板块的重量，大楼所需承受的高风压，以及单元往外悬挑的幅度会需要在公母立柱上建立高强度的固定连接，该连接将导致型材承受很大的弯曲应力，及在连接点上承受局部压力。如果单靠加大或加厚立柱横梁型材，或在立柱加上钢芯来加强立柱，得出的型材剖面除了显得过大而且影响观感外，还可能需要超大的型材模具，或导致经常性的模具破坏， 或因过量闭腔墙厚而导致型材质量参差，造成浪费。虽然图纸上只是几毫米的差别，但由于幕墙系统的节点於生产过程中将大量重复，这些设计考虑往往对系统的造价及可建性造成决定性的影响。

在一般加厚、加大传统型材不能满足设计要求的情况下，只有了解传统的公母型材切面设计所包含的多个功能法式，才可以根据相同的功能法式对上述的限制作出突破性的改动以配合设计要求。在此项目的设计条件下，虽然采用传统公母型材作为支撑悬挑部分的结构框架并不是经济的做法，但在防水的角度来说，保持传统公母型材里的均压腔还是有利的。有见及此，幕墙工程师在设计阶段时采用了一个连接到单元紧固件的刚性钢构架 （图6）来承托玻璃和外部封口的铝板部件的自重，以及整个单元板块所承受的风荷载。在此情况下，公母立柱和横梁型材不再担当结构上的功能，但仍然能拥有有关于防水的功能法式的节点。值得留意的是，最终幕墙承包商选择使用铝型材来搭建构架，该构架的设计逻辑依旧是按照幕墙工程师对功能法式的重新演绎原则来设计。

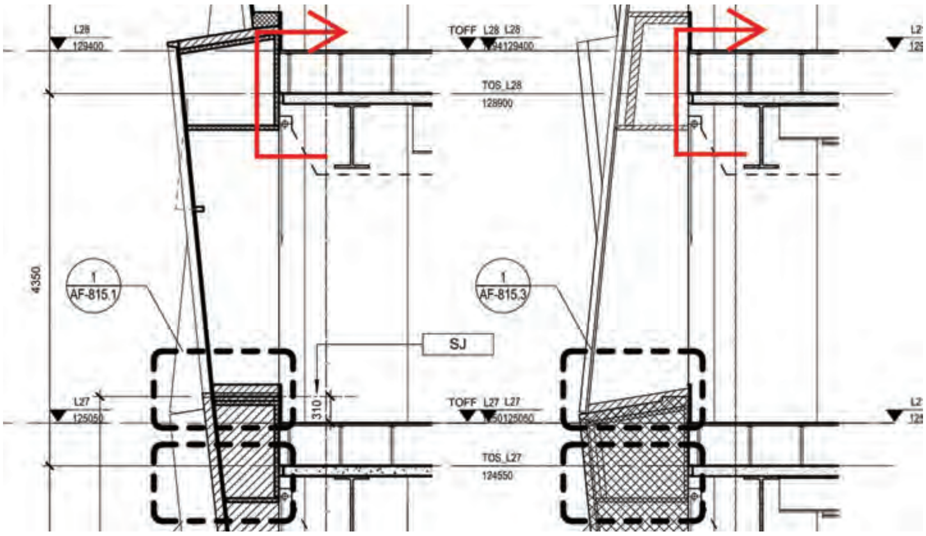

Figure 7. Cavity at the spandrel of curtain wall units (Source: NBBJ)
图7. 幕墙窗间墙部分的空隙（来源：NBBJ）

Floor-to-Floor Fire Separation Behind Curtain Wall

Another functional pattern that façade engineers often come across is floor-to-floor fire separation – a statutory regulation that is often manifested as a structural element, such as a 800-millimeter-deep concrete hangar wall below the slab (National Standard of the People's Republic of China, 2014)) having the same fire resistant rating as the floor slab, behind its curtain wall systems along the building's perimeter. The applicability, dimensions and efficacy of this element vary from one building code to another notwithstanding; in Hong Kong, for example, provision of floor-to-floor fire separation is applicable where the building is not sprinklered (Buildings Department, 2011). The common assumption behind this requirement is that curtain wall systems are statutorily allowed to be considered a sacrificial element during a fire, in which case an additional fire-rated element integral to the floor slab is to be introduced in order to prevent fire from spreading by "leaping" from one floor to another.

This would have been a straight-forward requirement under normal circumstances; however, in this case, the local fire department opined that the façade units protrude and form a cavity that may allow fire to leap across from one floor to another near the slab edge (Figure 7). For that reason, an extension fire-rated element between floors into the spandrel was required as a prerequisite for approval.

The repercussions of this requirement on the façade installation sequence and the system's interfacing with the main structure were immense; the fire-rated element extension – be it concrete or an assembly of fire-rated steel and insulation – would have hindered the installation of the façade units if it were to be installed before the façade, and vice versa.

After conceptualizing the construction sequence and devising multiple options to address the problem, the façade engineer came to the conclusion that the fire-rated extension element could only be achieved by installing it at the same time as the façade units. To do so, the façade engineer designed a temporary connection between the unit and the fire-rated extension element (a fire-rated steel and insulation assembly), such that the unit became a "vessel" for transporting the element to the required location as the unit is being hoisted to its final location. The team also designed special hoisting components and took into account the loading resulted from the additional assembly. As the façade unit was being installed, the temporary connections were released and permanent connections between a different set of brackets on the fire-rated extension element and cast-in elements on the slab were made (Figure 8). This is a concise example demonstrating how functional patterns are

幕墙背后的层间防火

另外一个幕墙工程师常用的功能法式是"层间防火"。作为一条规范要求，层间防火系统经常在沿着楼板边的幕墙背后以拥有与楼板同样防火耐火等级的土建结构的形式出现 （比如说楼板以下800mm深的悬吊混凝土墙体（中华人民共和国国家标准，2014））。纵使此防火元件的尺寸、有效性及适用性在不同的建筑规范有所不同（在香港规范里，层间火适用於没有安装喷淋系统的建筑物 （屋宇署，2011）），但背后共同的假设是如果幕墙系统在火灾时是容许被破坏的建筑元件，要防止火舌'跳'往上方楼层导致火灾蔓延的话，便需要在楼板边沿放置一个与楼板为一体的防火元件。

在一般情况之下此规范要求并不难满足。但是，在此项目条件下，当地消防部门认为由于幕墙单元板块悬挑於楼板之外，因此在楼板与幕墙之间形成了一个可容许火往上蔓延的空隙（图7）。因此，作为通过审批的条件，消防部门要求在窗间墙加上一个由楼板延伸出来的防火元件。

这个要求对幕墙安装次序以及幕墙与主结构的界面设计影响深远。无论是混凝土还是由钢件及防火面组成的组件，在幕墙单元到位之前或是之后安装，该延伸防火元件都会阻挡幕墙单元的安装。

在考虑过施工组织以及多个施工方案后，幕墙工程师的结论是该防火延伸元件必须与幕墙单元同时安装。要做到这点，幕墙工程师设计了暂时连接於幕墙单元板块，以钢材与防火面组成的防火元件。由此，幕墙单元在调运到适当位置的过程中同时把防火元件运到所需位置。设计团队同时也设计特殊的吊挂部件，并将该防火元件的自重考虑在工程计算里。幕墙单元安装的时候，工人将防火元件与单元板块之间的暂时性连接松开，并将防火元件上的另外一套连接件永久的固定在楼板的预埋件上（图8）。这个例子显示了在异常的设

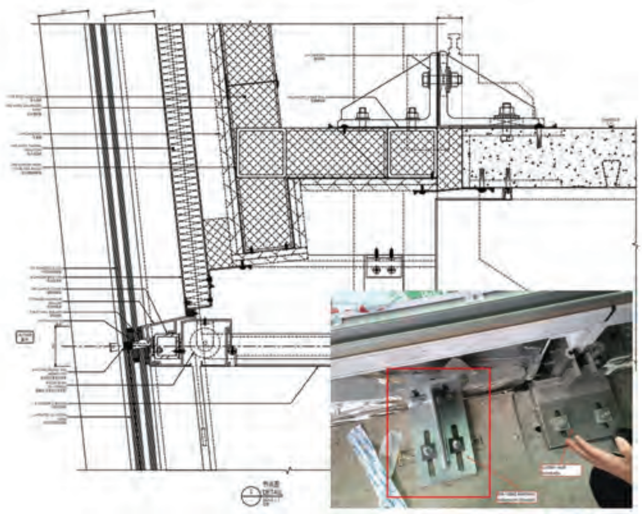

Figure 8. Fire-rated element extension and separate connection to floor slab (Source: Inhabit Group)
图8. 延伸防火元件及其与楼板的独立连接（来源：Inhabit Group）

achieved in an atypical scenario by revisiting conventional designs of façade components, then re-interpreting and modifying them to suit the installation requirements.

CW2

CW2 is a unitized system that is located on the eastern and western elevations of both the north and south towers, as well as the northern elevation of the north tower. This system is composed of approximately 32,960 square meters of glass panels, installed on pre-fabricated façade units. Instead of inclining inwards and outwards along the height of the tower, however, the panels on this system (which are of varying widths) zigzag along the slab edge on each floor to form a pattern that was referred to as "fish scales" by the contractor.

Not unlike CW1, standardization to facilitate pre-fabrication of façade units under factory conditions was a key to the successful delivery of this system. A system was again devised by the architect to ensure that a small number of panel types were used to create a pattern that is seemingly random on elevation (Figure 9).

Using the concrete slab and the steel edge beam below to create the intended zigzag profile on each floor would have been complicated: the accuracy of the profile would have depended entirely on the on-site workmanship; formwork construction and the casting of the concrete slab would have had been an unforgiving process; and installation of the steel edge beams would have been challenging as well. The architect, therefore, opted for using the façade units, which are prefabricated to high precision under factory conditions, to achieve the intended profile instead.

The challenges of CW2 then became similar to those of CW1: to design a cantilevered unit that necessitates separation of the structural framework of the unit and the waterproofing mechanism of the unit. A similar design was therefore developed by the façade engineer during the design stage (Figure 10).

Façade components are almost entirely standard, factory-made products. Although a certain degree of customization is inevitable in each project (such as aluminum extrusion profiles and silicone gasket profiles), façade designers hold a strong belief that "details should conform to norms that are known, understood, and accepted throughout the… industry" (Allen,1993), and that "by conforming to these norms and referencing them in the written specifications… the detailer eliminates many ambiguities and potential sources of misunderstanding from the construction document" (Allen,1993). Fabrication limits and the standards of fabrication procedures of factories in the region were therefore strictly adhered to.

计条件下如何按照功能法式重新考虑、重新演绎及修改幕墙组件的设计以达到要求。

CW2

CW2 是一个单元式幕墙系统。位于南塔的东、西立面及北塔的北、东、西立面。此系统有 32960 平方米安装在单元板块的玻璃组成。但是此系统不像CW1一样朝上下倾斜，而是以宽度不同的板块在每层平面呈锯齿状往外悬挑，形成一个承包商昵称为‘鱼鳞’ 的纹理。

与CW1相似的是，将幕墙板块标准化以简化单元在工厂的加工程序是成功建造此系统的要诀。建筑师也同样在设计初期引入了简化板块类型的系统，同时不影响幕墙在观感上的随机性（图9）。

以混凝土楼板或者是钢梁来营造锯齿形的楼面轮廓将会是一个非常复杂的工序。轮廓的准确度将完全依赖现场施工的水平；混凝土模板施工及浇注允许误差需要大大降低，安装钢件的挑战性也相对大。所以，建筑师决定使用在工厂情况下精确生产的幕墙单元板块来营造所需的锯齿形轮廓线。

因此，CW2 在技术上的挑战与CW1相约 – 在悬挑单元的结构框架与防水系统宜分开处理。幕墙工程师於是在设计阶段设计了一个原则上跟CW1系统一致的系统（图10）。

Figure 9. CW2 fish scale pattern (Source: Inhabit Group)
图9. CW2 鱼鳞纹理（来源：Inhabit Group）

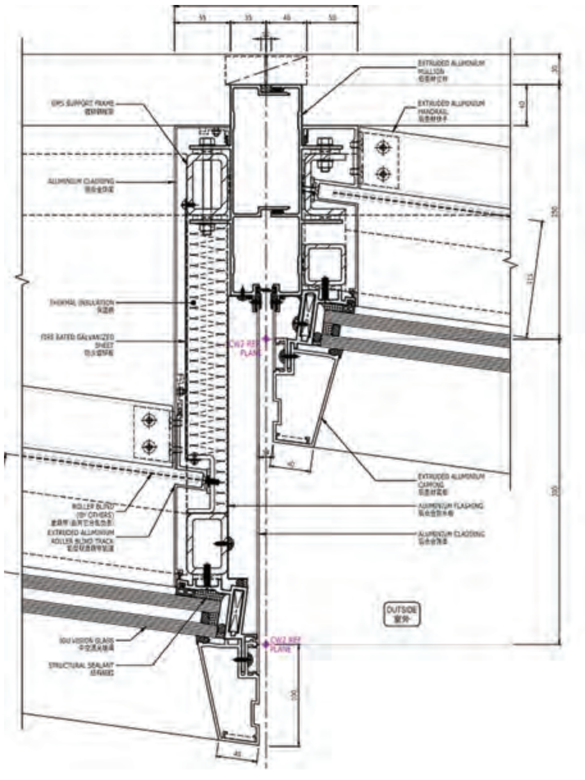

Figure 10. Steel frame support connected directly to unit brackets (male and female mullion extrusion for creation of PEC only) (Source: Inhabit Group)
图10. 刚性钢构架直接连接到单元的连接件。公母料只用于提供均压腔（来源：Inhabit Group）

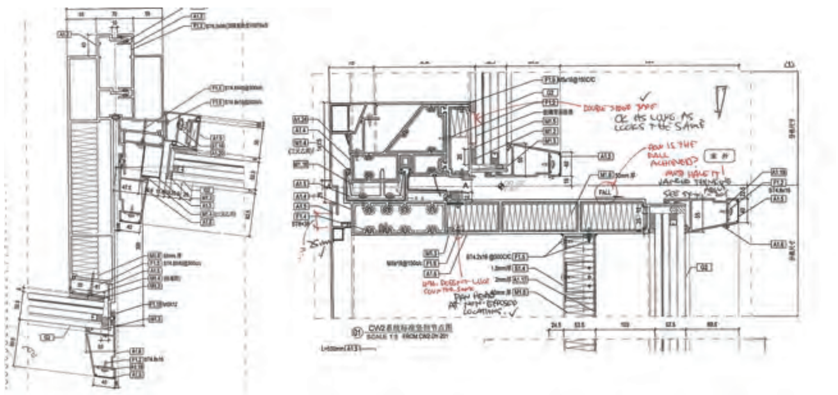

Figure 11. Oversized mullion and transom extrusion developed by the façade contractor (Source: Jangho Group)
图11. 承包商开发的超大立柱与横梁型材（来源：江河集团）

It is worth noting that as a normal practice in South China, façade engineers are often responsible for checking the contractor's shop drawings and engineering design calculations during the construction process in order to ensure that the solutions proposed by the façade contractor are sufficiently researched, verified, and practical from a QA/QC point of view. Given that the normally acceptable size of aluminum extrusion die is limited is 250 to 300 millimeters in diameter, the façade contractor's counter-proposal to use approximately 500-millimeter-deep mullions and approximately 575-millimeter-deep transoms for the extrusion profile came under scrutiny by the façade engineer (Figure 11).

The risks associated with over-sized aluminum extrusions are well documented; they are likely to require extrusion press of higher press tonnage which may not be available in the region, as well as stronger steel die which are less vulnerable to breakage due to the high press tonnage, which may be more costly than regular die. Furthermore, it is more difficult to keep over-sized extrusions straight as they exit the press, especially for extrusions with multiple closed chambers; therefore, the use of over-sized aluminum extrusions would require a higher level of quality assurance and control, and would almost certainly result in greater waste. The design team was concerned that these challenges may hinder the production process and result in delays in unit production and fabrications.

Despite the technical challenges, using over-sized extrusions can greatly simplify the fabrication process compared to using a structural frame similar to that of CW1's. The contractor rightly pointed out the fact that the CW2 units are triangular in footprint. Knowing that the profile of the top transom on plan is identical to that of the bottom transom, the transom extrusions were designed as such that they could be split diagonally in half and be used at the top and bottom transom of each unit (Figure 12). Furthermore, despite the different panel widths across the elevations, the cantilevering distances of all CW2 units are identical according to the architect's design intent, so the over-sized mullion extrusions could be standardized and used on all CW2 units. These advantages in terms of fabrication, as well as the sheer number of CW2 panels that could be

幕墙组件是标准、工厂生产的产品。虽然每个项目都牵涉一定程度的特别设计（比如型材轮廓及硅胶胶条等），幕墙设计师相信“节点应该遵照已知、有参考范例及业界认可的的范式设计”（Allen, 1993); “通过遵守这些范式，同时在技术要求里提出相关的参考… 节点设计师可以排除大量模糊点以及在施工文件中有可能导致误解的地方”。

值得留意的是，在施工过程中由幕墙工程师负责检查承包商的施工图及工程计算在南中国是一个相当普遍的做法。用意是为了确保承包商的建议方案经过足够的论证，在设计，施工以及品质控制上是可行的。所以，当承包商建议在 CW2使用分别 500mm 深及 575mm 深的型材作为单元的立柱与横梁 （铝型材一般铝型材厂的钢模尺寸控制在直径250mm 到300mm左右），幕墙工程师立即与承包商针对生产、加工、质保、施工等展开了一系列严谨的研究及论证过程（图11）。

使用超大铝型材的风险有很多的记载。超大型材可能需要较大的模具以及压力较高的型材挤压机生产；为避免造成模具破坏，模具的强度也必须相应增加，模具的价格也可能因此上升。再且，超大型材挤压出来的时候难以保持平直，尤其是有多个闭口腔的超大型材。所以，使用超大铝型材需要高水平的品质控制，而且型材的报废率也相对的高。

虽然技术上的挑战性很高，与CW1比较，使用超大型材在此系统上的确可以大大简化单元的加工过程。承包商正确的指出因为CW2 板块在平面上是三角形的，而且上横梁的轮廓在平面上与下横梁是一模一样的，横梁型材可以对角线切开，一半用在顶部，另一半用在底部（图12）。纵使板块的宽度在平面上大小有别，CW2 所有单元悬挑的距离都是一样的。所以，超大立柱型材可以标准化使用在所有 CW2

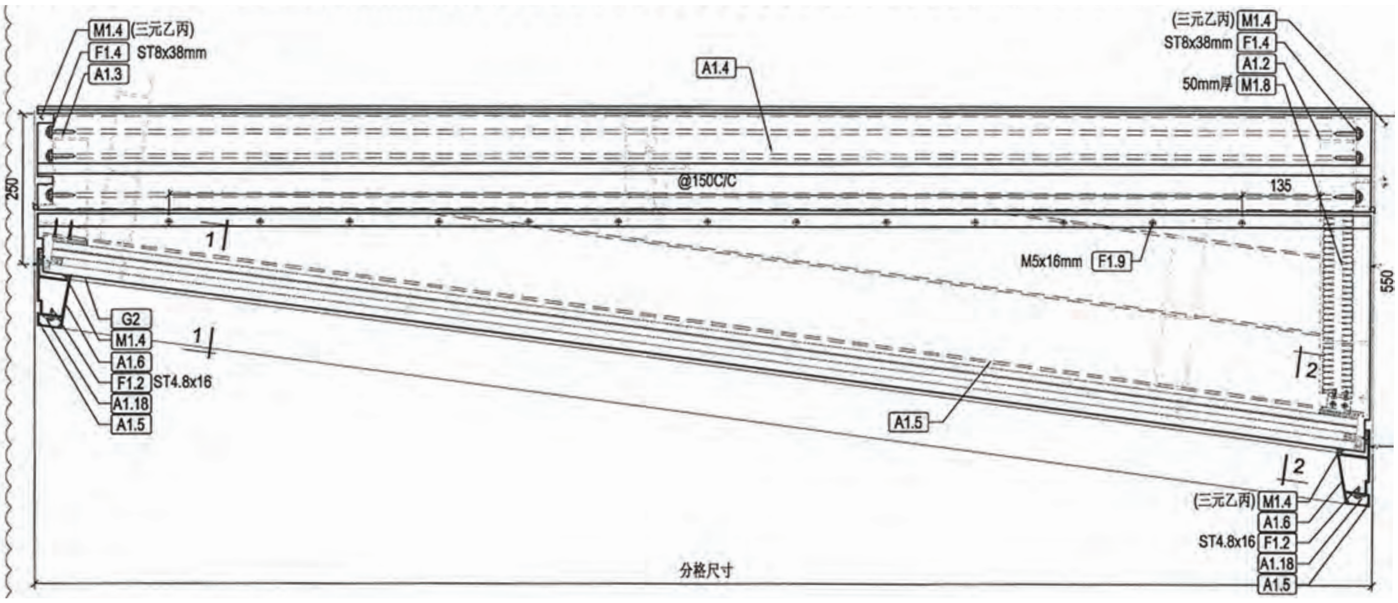

Figure 12. Diagonally split extrusion (each half of the split extrusion is used as the top and bottom transom, respectively) (Source: Jangho Group)
图12. 对角线分割的超大型材。型材一半用于上横梁，一半用于下横梁（来源：江河集团）

simplified or standardized, would more than sufficiently justify the experimentation with over-sized extrusions.

To demonstrate that the proposal conforms to the performance and QA/QC requirements outlined in the façade engineer's technical specifications from design, production, and assembly to installation, the façade contractor worked closely with the façade engineer for months to review potential extruders that were qualified for producing over-sized extrusions. A reputable aluminum extruder equipped with a press with 9,000 press tonnage and the QA/QC personnel and procedures necessary for the operation of the extrusion press was eventually selected for extrusion production.

The extruder produced a series of mock-ups of the required extrusions to demonstrate their capacity, thus making it possible to produce extrusions from maximum one-meter DIA die. To further ascertain the performance of the units using over-sized extrusions, structural and waterproofing performance tests were carried out on a performance mock-up. On top of that, load tests were carried out to ensure that the cantilevered units would not be susceptible to permanent deformation when anticipated loading is applied at the end of the cantilevered length. After a rigorous process of technical verifications, the contractor's counter-proposal was accepted.

Conclusion

As the examples above have shown, understanding façade detailing as applications of combined functional patterns is important to ensuring the performance of the system designed. These functional patterns, which are essentially technical principles for which the design should adhere to, do not always necessitate the use of a set of one-size-fit-all standard template details. They are meant to provide a basis for designers to invent and adjust details to suit the specific needs of the project.

Due to a tight project schedule, however, designers are sometimes tempted to "short-hand" these functional patterns into standard details or rules of thumb that are applied without further considerations on the behind operative principles. Although this practice may be efficient for dealing with buildings that are geometrically simple with typical functional requirements, the architectural design intent and the performance requirements would inevitably be compromised if designers attempt to copy-and-paste standard details for buildings that are geometrically complex or with non-standard functional requirements.

Therefore, where the design calls for atypical solutions, it is beneficial for the façade engineer to deconstruct the standard details and rules of thumb and re-interpret the functional patterns behind them, so that the resulting details may creatively follow the very principles on which the functional patterns are based on.

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单元。这些生产上的优势，加上可以被简化及标准化的CW2单元的数目，提供了足够理由针对超大型材进行论证及研究。

为了证实其建议方案可以严格跟从幕墙工程师的技术要求里提出对设计，生产，加工及安装上的效能及质量控制要求，幕墙承包商与幕墙工程师合作审核有能力生产超大型材的铝型材生产商。一家备有9000吨压力挤压机，并有相应的质空人员制度的生产商最后被批准生产此系统的铝型材。

其后该生产商在正式生产前造了一套所需型材的样板以展示其质量。为了进一步确定使用超大型材的单元的效能，承包商建造了一个性能测试样板，按幕墙工程师技术要求及当地规范要求进行了针对结构、防水、气密及位移等的性能测试。除此以外，还针对悬挑部分进行了荷载测试，务求证实悬挑部分在承受荷载时不会造成永久性的变形。经过一系列严谨的技术验证，承包商的建议最终得到接纳。

结论

由以上的例子可见，把幕墙节点设计理解成不同的功能法式的复合应用对确保系统效能是十分重要的。这些功能法式主要是设计应该遵从的技术原则，所以并不一定以使用一式一样的标准节点去实现。功能法式提供的是一个设计的依据，让幕墙设计师可以按此调整及发明新的节点来配合不同项目的需要。

但有时因时间关系，设计师有诱因在没有深入考虑背后原则的情况下把功能法式简化成标准节点及经验法则。此做法在几何及功能要求简单的建筑物上可以达到一定的效率，但针对非典型几何，功能要求复杂的建筑物，盲目的应用标准节点将不可避免地不能满足建筑师意图及所需的技术要求。

所以，在设计需要非典型的解决方案时，幕墙工程师应解构标准节点及一般的经验法则，找出背后的功能法式并适当的重新演绎，令最后得出的节点可以地跟随功能法式满足个别项目的要求。

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