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# City of Dreams, Macau: Maintenance Design in Ultra-Complex Structures | 澳门新濠天地：超复杂结构中的维护方案设计



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Isabella Pallavicini is a professional in the field of façade maintenance, specializing in rope access systems. She is a civil engineer and achieved a PhD degree at the Polytechnic of Milan. After a period doing research, she gained a position as Adjunct Professor at Sapienza University of Rome, where she focused mainly on hydropower systems. Besides these areas of interest, she cultivated the field of health and safety systems for work at height, focusing on façade access issues. She is founder, CEO and CTO of Fly Service Engineering srl, the first engineering company to develop access systems using rope access.

外立面维护领域的专业人士，专门负责绳索作业系统。她是一名土木工程师并在米兰理工学院取得博士学位。在担任了一段时间的研究员后，Isabella成为罗马撒宾萨大学（Sapienza University of Rome）的兼职教授，主要从事水电系统的研究。除了这些研究领域和兴趣外，她也研究高空作业的健康和安全系统，主要着眼于外立面作业的相关问题。她是FLY SERVICE Engineering有限责任公司的创始人、首席执行官兼首席技术官，这家公司是第一家开发绳索作业系统的工程公司。



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Gianpaolo Apollonio is an entrepreneur in the field of rope access. He is the founder of the first and largest abseiling company in Italy, opening the national market on this specific field. Taking advantage of the experience gained in rope access works, he founded Fly Service Engineering srl, the first engineering company that develops access systems using rope access, with an extensive series of relevant projects carried out internationally. He develops new solutions driving the R&D office.

他是绳索作业技术领域的一位企业家。他也是意大利最早、规模最大的绳降公司的创始人，打开了意大利在这一特定领域的全国市场。凭借着在绳索作业中取得的丰富经验，他创建了FLY SERVICE Engineering有限责任公司。这家公司是第一家开发绳索作业系统的工程公司，并且已成功完成了多项国际项目。他开发新解决方案，领导 R&D 的研发部门。



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他是在外立面领域的企业家、咨询师和顾问。1994年，他在意大利成立了全球第一家外立面材料综合公司；1998年，他在澳大利亚发展了外立面材料公司的第一个国际网络；2003年，他在阿联酋也发展了一个国际网络……他总是积极关注行业内最新的产品和服务，目前，他担任FLY SERVICE Engineering有限责任公司国际业务发展部的主管一职。

## Abstract | 摘要

The issue of developing a safe and efficient access strategy considering the context of a complex shape is addressed. In these cases, all envelope and structure maintenance operations need careful engineering strategies and planning to develop safe and efficient procedures while reaching and managing 100% of required surfaces. A good level of interaction with the architect is fundamental to achieving the best results in terms of integration and efficiency of the access system. The case study of City of Dreams in Macau, designed by Zaha Hadid Architects, is illustrated, with the description of the solutions and technologies applied. How innovative technologies, such as rope access coupled with the development of bespoke devices and accessories can substantially improve safety, aesthetic impact, cost efficiency, building maintenance life cycle, comfort for operators, and energy saving is discussed.

**Keywords:** Building Maintenance, Façade Access, Life Safety, Service Life

本文探讨如何在复杂的结构和形状中实施安全有效的维护作业策略这一问题。在本文提及的案例中，所有建筑外层和结构的维护措施都需要仔细的工程策略设计和规划，以开发出安全、高效的程序，同时能够接触并管理所需处理的所有表面。与建筑师的有效互动程度对于在接近系统的整合和效率方面获得最佳结果非常关键。本文将澳门新濠天地为例进行分析，该建筑由扎哈·哈迪德建筑事务所（Zaha Hadid Architects）设计，对使用的解决方案和技术进行了描述：如何通过创新技术（例如在绳索上加入定制设备和配件）大大提高安全性、美学效果、成本效益、楼宇维修生命周期、工人作业的舒适度和节能效果。

**关键词：**建筑维护、立面开洞、生命安全、使用寿命

## A New Approach for the Façade Access Issue

Interpreting the spirit of contemporary architecture, the current design of buildings is increasingly a continuous research on aesthetic, functional and technical issues to give new visions of the built environment. The actual trend results in impressive geometries that combine innovation, creativity and sustainability, where the technical difficulties require not only a solution but also aesthetic integration to create harmonious constructions. Nonetheless, design and engineering are two aspects of the same issue that must necessarily be treated in strict correlation.

Considering these premises, the approach that should be followed when dealing with a very technical and operational issue such as façade access strategy – set forth also by international regulations (CDM, 2007) – should not require architects to stifle their creativity, limit their design freedom or compromise aesthetics for safety; but to eliminate hazards where feasible and reduce unavoidable risk, with an integrated approach that combines safety first with up-to-date technologies,

## 接近外立面的新方法

在解读当代建筑的精神时不难发现，当前的建筑设计越来越关注美学、功能和技术问题，旨在为整个建筑环境带来新的视野。正是在这样的背景下，当前的建筑设计趋势将创新、创造性和可持续发展相融合，建筑外形也呈现出令人印象深刻的几何形状，但技术难题不仅需要一解决方案，还需要融入审美，从而呈现出充满和谐感的建筑。但同时，设计和工程也是建筑的一体两面，因此，必须结合两者进行考虑。

鉴于此，在处理诸如接近策略之类的极具技术性和操作性的问题时——国际条例（CDM，2007）也同样提出了此问题——不应扼杀建筑师们的创造力、设计自由或出于安全考虑牺牲建筑的美观；相反，需要做的是在可行的情况下消除隐患、降低不可避免的风险，将安全考量与最新的技术、审美和功能性相结合，以综合的方法解决此问题。因此，建筑师和设计师们需要具备额外的专业知识和维护过程方面的经验，以评估在建造、维护和清洁方面可能出现的潜在危险，确保建筑在建造和维护过程中的安全，平衡建筑需求和安全需要，让维护系统更加高效安全。

aesthetics and functional issues. To do so, architects and designers need additional expertise and experience of the maintenance process to assess what the potential hazards will be during construction, maintenance and cleaning, to assure that there is at least one safe way of constructing and maintaining their design, balancing the architectural and safety needs, for an effective and safe maintenance system.

In this direction, one of the most promising access techniques that is becoming more popular and successful over the last decade is rope access. Rope access is considered by HSE UK the safest system for work at height considering the procedures, and this is supported by IRATA statistics (IRATA, 2013; HSE, 2003). Safety, coupled with higher speed of operation and the possibility of reaching any point of the building, are extra benefits greatly appreciated by building owners. It relies on the most advanced up-to-date technologies in terms of equipment, and the workers are highly trained professionals (Burnett, 2003). The systems required by rope access are almost invisible when compared to BMU roof structures and do not change at all the aesthetics of the building. If this technology is combined with a suitable engineering that integrates the strategy and all the access devices into the design of the façade from the first phase of the design process – to make sure that the access system interfaces effectively with other technical requirements – the results are quite interesting, especially for complex shapes: safety, efficiency, aesthetics and cost-effectiveness are fully achieved (Kassem and Mitchell, 2015).

## The Rope Access Approach

By using a rope access technique as a method of work at height, an efficient maintenance strategy for any shape, height (including supertall buildings) and size of building can be achieved, while implementing higher work-at-height safety standards, leaving unaltered the geometry originally designed, and ensuring replacement of all parts of the building envelope in the course of its life. The analysis of maintenance strategies should always keep as main factor the highest safety standards of work at height: using rope access we achieve the ability to recover operators in a very short time, at any position on the building and at any time of the working procedure as set forth by international Regulations, such as Directive 2009/104/EC (European Parliament, 2005) and Work at Height Regulations 2005 (HSE, 2005).

The aesthetics of the building are respected due to very low visual impact of custom machinery: all that is needed are small permanent accessories, while other equipment is temporarily assembled.

Rope access is a versatile system for working at height. It can usually cope with several changes of direction by the provision of small anchor points/deviators on undercuts or over-hangs. In the case of sloping surfaces, no additional provision is required as long as the designer provides for man/weight pressure.

Anchorage versatility is also a strong feature of a rope access system with considerably fewer anchors necessary than for cradles. A well designed rope access system can use structural features or members not necessarily close to the part to be accessed.

Flexibility in the number of operatives on-site at any one time is another prerogative. This has distinct advantages by shortening the time needed for both cleaning and replacement. In addition, set up, moving of principal anchorage area, and de-mounting time as well as progression on ropes is quicker. This aspect implies the benefit of reducing the time each worker is exposed at height. Finally, it could also be argued that the less time required for an area to have people working at height means that the overall risk is reduced for all concerned.

The quality of the cleaning is very high. In the majority of cases, rope access puts the operative in closer contact with the building, which allows for greater attention to the cleaning method, thus ensuring a better quality of clean.

Rope access generally suffers less damage from the passage of rope access workers in comparison to traditional techniques. This is a result of the controllability of a rope access worker even in windy conditions, the ability to absorb small impacts with the building, and a better control of movements by closer contact. In any case, proper provisions to avoid damages to the building are essential and must be made through the development of proper temporary edge protections.

Capital costs and operating costs are greatly reduced compared to equivalent traditional systems. The simplicity of the system allows for this normally, avoiding costs deriving from local structural reinforcements.

The operating costs are reduced as well as the costs for maintenance and inspection of the system, as there isn't much to a rope access system that can be considered a

在这方面，近十年来越来越流行并取得巨大成功、最有前途的维护作业技术之一就是绳索高空作业技术（rope access）。绳索技术被英国HSE认定为建造过程中最安全的高空作业系统，并有拥有IRATA的数据作为支撑（IRATA, 2013; HSE, 2003）。这种技术不仅有安全保证，而且拥有更快的作业速度，还可以接触到建筑物的任何地方，这些特色也是建筑所有者们最欣赏的优点。这项技术需要依靠最新、最先进的设备技术，同时作业人员要经过非常专业的训练（Burnett, 2003）。相较于BMU屋顶结构，这种绳索系统更无形，并且完全不会影响建筑的美学风格。如果能在设计过程的最初阶段就把这项技术与合适的工程相结合，将设计策略与所有接入装备都融合在建筑外立面的设计中，那么一定会收获很好的效果，特别是具有复杂形状的建筑：既能够满足安全性、高效性，又兼具美观性和成本效益。

## 绳索高空作业方式

无论建筑物的形状、高度（包括超高层建筑）、规模如何，在高空作业时使用绳索技术都可以进行更有效的建筑维护，在充分保证符合高空作业安全标准的同时，保留几何形状的原设计，确保在建筑的寿命周期中可以替换建筑外层的所有部分。在分析维护策略时，一项主要因素就是高空作业时的最高安全标准：通过使用绳索，我们可以在很短时间内，在建筑的任何位置和工作流程中的任何时间救援作业人员，这也符合国际条例中的相关规定，参见第2009/104 / EC号指令（欧洲议会，2005年）及2005年高空作业规定（HSE，2005）。

建筑呈现的美感来自于定制装备极小的视觉冲击效果：所需的的就是小的永久性配件和其他临时组装的配件。

绳索接入是高空作业的一个功能多样全面的系统，它可以通过底切或外延部分上的小锚点 / 转向装置处理方向上的变化。在斜面上，只要设计者规定了人体 / 重量压力，就可以不需要额外工具。

锚定系统的多功能性也是绳索技术系统中的一大特点，相对支架的使用，绳索使用更少的必要锚具。一个设计良好的绳索系统可以充分利用结构特征或结构各部分的特点，而不一定要靠近需要接近的部分。

这一系统的另一大优势是在任何时候、任意地点进行作业的灵活性。这种特点可以有效缩短清洁和替换部件的时间。此外，设置和移动主锚区以及拆卸绳索和在绳索上移动的速度更快。这些都意味着减少每个工人的高空作业时间。而让工人们在更



permanent feature other than the anchorage system itself, which rarely has any moving or electrical parts. The same can be said for electricity consumption due to the absence of machines or electric motors, drastically reducing maintenance time and streamlining the work processes.

With the exception of the US, where the hourly rate for rope access workers is the same of BMU workers (they are part of same union), in the majority of the world the hourly

rate is on average approximately 20% more expensive. This is balanced however, taking in consideration the greater speed of operations (on average no less than two times faster in our experience). The operational cost is therefore greatly reduced compared to BMUs.

### The City of Dreams, Case Study

The City of Dreams (COD) Hotel Tower is part of a large-scale entertainment resort in Macau, currently under construction, built and owned by Melco Crown Entertainment. The tower, designed by Zaha Hadid Architects, is a 40-story hotel with a gross area of 150,000 square meters including guest rooms, suites and villas, gaming rooms, lobby atrium, meeting and event facilities, restaurants, spa and sky pool.

The building is mainly a monolithic block with a series of voids which carve through the center of the tower to create a sculptural form (Figure 1). The shape is completed by an exposed exoskeleton, separated from the façade, that wraps the entire building (Figure 2).

In the interior area an expansive entrance brings guests inside a 40-meter high atrium. The building is split between two distinct cores – either side of the atrium – which connects to the hotel accommodation floors

短的时间内完成高空作业也就意味着工程整体风险的降低。

此外，清洁质量非常高。因为在大多数情况下，使用绳索作业技术可以让工人更贴近建筑，因此可以更细致地进行清洁，保证高质量的清洁。

与传统技术相比，使用绳索对建筑造成的损害更小，因为即使是在刮风的天气下，也可以控制绳索上的工人，并且能够吸收对建筑物的小冲击，此外由于靠近建筑物更近，也能更好地控制移动。在任何情况下，恰当的准备对减少对建筑物的损害非常关键，并且需要采取一些临时边缘保护措施。

与传统技术系统相比，使用绳索技术也让资金成本和运营成本大大降低。正因为该系统操作简单，所以在施工中经常会使用，也避免了因局部结构加固产生的额外成本。

使用绳索技术降低了运营成本，也减少了维护和检查系统的费用，因为相对于锚固系统，绳索技术系统的检查要简单很多，也很少有移动的部件或电气部件。同时，由于不需要使用机器设备或电力发动，电力消耗也很小，并且大大减少了维护时间，简化了工作流程。

除了在美国绳索工人的时薪与BMU（高空作业平台）的工人时薪相同外（两者同属一个联盟），在世界上的大部分地方，绳索工人的时薪平均要高出20%，但考虑到绳索作业的速度更快（根据我们的经验，平均速度至少要在两倍以上），更高的时薪得到弥补。因此，运营成本相较于BMU依然大幅降低。

### 案例分析：新濠天地

新濠天地酒店大楼是澳门大型娱乐度假胜地的一部分，目前正在建设中，由新濠博亚娱乐建造并所有。该大楼由扎哈·哈迪德建筑事务所设计，是一个40层楼高的酒店，总占地面积为15万平方米，包括客房、套房和别墅、游戏室、大堂中庭、会议室、活动设施、餐厅、水疗中心和空中泳池。

该建筑的主体是一个整块，在大厦中心有一系列的空隙，创造出雕塑形状（图1）。暴露的外骨骼的网状结构从外立面分离，包裹着整个建筑（图2）。

在内部区域，广阔的入口将客人们带到40米高的中庭。该建筑被分为两个不同的核心区域，分别位于中庭的两侧，将酒店的住房楼层和贵宾博彩区相连接，在全景电



Figure 1. General view of the tower (Source: Zaha Hadid Architects)

图1：大楼的总视图（来源：Zaha Hadid 建筑师事务所）

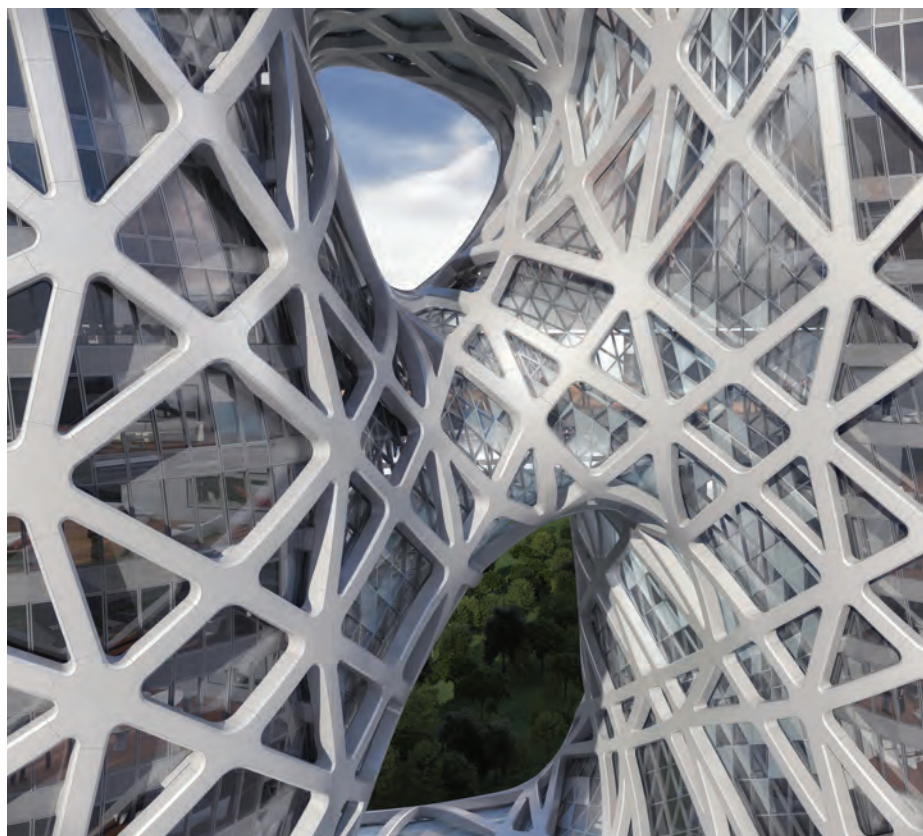


Figure 2. Detail of the façade (Source: Zaha Hadid Architects)

图2：外立面的细节（来源：Zaha Hadid 建筑师事务所）



and VIP gaming areas, while panoramic lifts have views of the voids when ascending the tower (Figure 3).

The features of the building, especially the free-form, the exoskeleton, and the huge and complex internal spaces of the atrium, make the access strategy an extremely challenging issue that requires the adoption of bespoke solutions.

The client and the architect brief was calling for a rigorous maintenance strategy to preserve intact the aesthetic appeal over time, the need for an efficient and rapid reaction maintenance strategy, and cost effectiveness, all without interfering with the aesthetic and structural elements of the building.

### The Access Strategy

The main goal is to design a system for the maintenance that is primarily safe and easy to use, to allow any qualified subcontractor that will do the maintenance to operate safely, easily and efficiently. Standing the complexity of the surfaces to move on and to reach, the design of the access system was developed following some guiding principles that aim to obtain full safety independently from the skill of operators. These criteria are those usually followed also for other access techniques (Herzog, 2008).

Intuitiveness – all devices to be used and the methodologies for the progression are described in detail in the final maintenance handbook supplied at the end of the executive design. Nonetheless, the system must be as intuitive as possible, so that the possibility of a mistake is minimized, even in the case that the operative omits some concepts and instructions reported in the handbook or if some information is not understood.

Simplicity – to avoid errors during operations or complications that can induce the operator to incidentally or deliberately undertake actions that can expose himself to risk, the system must be as easy as possible. This is done by: a) Reducing the kind and number of devices that the operator must use; b) avoiding changes of devices during the operation; and c) avoiding difficult maneuvers that require extra skills.

Redundancy – each safety device must be designed with reasonable redundancy according to the maximum number of persons operating; in all cases according to international standards.

Despite the areas' demarcation according to location and type of façade, the access strategy cannot be treated separately for each zone, but must be addressed globally. Therefore the external access of the free-form is connected to the access of the internal atrium, and the accesses of the various areas of the internal atrium are connected to each other.

The conceptual procedure for determining the access strategy and the access system passes through the following steps:

1. Establish general routing for each part: (access, progression, egress) – this phase is made in coordination with other consultants and takes into account operational, logistic and construction constraints.
2. Define the best operative abseiling procedure – this is done in strict coordination with expert abseilers.
3. Define the permanent devices on the façade (e.g., access hatches, safety devices, anchor points) – again in coordination with architects and consultants involved in the façade design.
4. Define specific abseiling tools and the temporary accessories to use.

It is very often the case, as for COD, that the permanent devices on the façade and the temporary accessories are custom-made to minimize the aesthetic impact, matching with the main structure design and optimizing the performance of the access system.

梯上升的过程中可以看到整栋建筑的空隙设计 (图3)。

建筑的特点, 尤其是自由形态、外骨架、中庭巨大而复杂的内部空间, 让接近外立面成为极具挑战性的问题, 需要通过定制方案来解决。

客户要求通过严格的维护来完整保留建筑物原本的美学特色, 并且要建立快速有效的维护措施, 在保证不破坏美学设计和建筑结构元件的前提下达到成本效益。

### 维护作业策略

主要目标就是设计一套维护系统, 首先要确保安全和易于使用, 让今后负责进行维护的任何分包商都可以安全、方便、高效地进行作业。鉴于需要在其上移动或需要接近的建筑表面的复杂性, 在设计接近系统时遵照了以下几项指导性原则, 旨在让操作人员获得完全的安全保障, 不管他本身技能如何。这些标准通常也是其他维护作业技术中需要遵循的 (Herzog, 2008)。

直观 – 所有将会使用的设备以及移动的方法都会详细写在最后的维护手册中, 该手册在执行设计结束时提供。但是系统必须尽量直观, 即使操作人员忽略了手册中出现的一些概念或者说明, 或未正确理解手册中的某些信息, 也能让错误发生的可能性降到最低。

简单 – 为了避免操作失误或由于操作太繁复导致工人无意或有意采取危险行动, 系统必须尽可能简单。为此: 1) 减少工人必须使用的设备种类和数量; 2) 避免



Figure 3. Internal atrium (Source: Zaha Hadid Architects)  
图3: 内部中庭 (来源: Zaha Hadid 建筑师事务所)



Figure 4. Bespoke anchor point (Source: FLY SERVICE Engineering srl)

图4. 为自由形态定制的锚点（来源：FLY SERVICE Engineering srl）

For the external façade of COD the main issue is the complexity of the shape, in particular:

- The free-form is extremely complex and wide. The anchor points on that part can be placed only on the steel members that carries the glass and in specific locations due to possible clashing with other façade elements and to structural issues of the beams.
- The presence of the exposed exoskeleton that is separated from the façade, – an approximately square section of side 900 mm, separated from the glass with a gap of 300 mm – and a cladding that cannot be used for fixing any anchor point.

These aspects led to a very careful definition of the access strategy; a 3D study for the positioning of the access hatches and anchor points, shared and carefully revised by all other consultants involved in the façade design; bespoke anchor points; and brackets to optimize the integration with the façade. For example, a special anchor point was developed for this part of the façade that has a double function: structural anchoring and deviating (anchors are the roof mounted system to carry the load of workers and materials handling, deviators provide the ability to move away from vertical lines) (Figure 4, 5). This special device combines the need of having the smallest number of anchor points on the façade with the possibility of deviating the ropes without knots, which would have hugely increased the difficulty of abseiling and the duration of a single climb down. Special deviators were developed also for the exoskeleton to minimize the impact on the structure, fixing the devices on the internal system of brackets with no impact on the external cladding (Figure 6).

For the internal atrium, due to the extremely complex geometry of the internal spaces, there is a variety of access difficulties ranging from the free-form façade, to the false ceiling of the bridges, to the elevators shafts, to a



Figure 5. Deviators in the exoskeleton (Source: FLY SERVICE Engineering srl)

图5. 外骨架上的转向装置（来源：FLY SERVICE Engineering srl）

在作业中替换设备；3）避免需要额外技能的操作。

冗余设计 – 每个安全装置都必须根据同时作业最大人数，设计合理的冗余。任何情况下都应符合国际标准。

尽管每个区域是根据不同的位置和外立面类型来划分的，但在设计接近策略时不能对每个区域进行单独处理，必须从整体上考虑。因此，对自由形式的外部接近和对内部中庭的接近及内部各个区域的接近都是彼此关联的。

用于确定维护作业策略及系统的概念性程序，通过以下步骤完成：

1. 为每一个部分建立通用路线（进入、前进、退出），该步骤需要与其他顾问进行协调并考虑到操作、物流和建造方面的限制；
2. 确定最佳沿绳下降过程，该步骤需要与绳降专家共同协商完成；

3. 确定外立面上的永久装置（比如入口、安全装置、锚点），该步骤需与建筑师及参与外立面设计的顾问协商完成；
4. 确定临时使用的配件和具体的绳降工具。

对于新濠天地而言，通常在外立面使用的永久装置和临时配件都是定制的，这样可以减少对建筑美观的破坏，与主体结构设计更加匹配并可以优化外立面作业系统的性能。

对于新濠天地的外立面而言，最主要的问题就是外在形状的复杂性，尤其是：

- 自由形态：极其复杂、广泛。由于可能会与外立面的其他元件发生冲撞以及横梁的结构问题，该部分的定位点只能在承载玻璃的钢化元件上，并且需要置在特定位置上。
- 暴露的外骨架与外立面分离，大约900mm侧截面，玻璃与其的缝隙距离为300mm，此外还有一个不能固定任何锚点的包层。

正是这些因素的存在，在制定外立面作业策略时要特别小心，因此参与外立面设计、定制锚点和托架以优化和外立面的整合的所有其他顾问们共享并修订了一份对入口和锚点位置的3D研究。比如，在外立面的这部分使用了一个具有双重功能的特殊定位点（图4、5）：结构锚定和转向系统（锚具为屋顶安装系统，它可以支撑工人和使用材料的重量，而转向装置能够实现偏离垂直线的移动）。这一特殊装置结合了在外立面使用最少锚定点的需求，并且在绳索上进行偏离作业时不会打结，因



Figure 6. Anchor point integrated into the façade (Source: FLY SERVICE Engineering srl)

图6. 嵌入外立面的锚点（来源：FLY SERVICE Engineering srl）



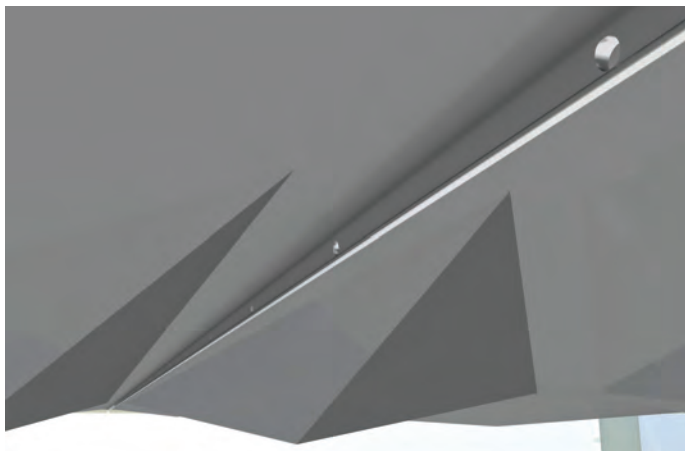


Figure 7. Integration of a linear anchor point into a false ceiling (Source: FLY SERVICE Engineering srl)

图7: 在人工吊顶上嵌入线性锚点 (来源: FLY SERVICE Engineering srl)

series of minor but equally important access problems on smaller areas. All were solved with a strict coordination with the architect and other consultants involved. The entirety of the internal area is made accessible with rope access.

As an example of embedding of anchor points, the false ceilings are a good case study. A series of linear anchor points, specifically developed, are inserted along the lines that create the aesthetic pattern, mainly composed of diamonds. The layout was shared with the architect to obtain the most efficient and least visible access system (Figure 7). The colors are the same as the ceiling panels, and the anchor points are conceived into the joint in suitable recesses.

## The Replacement Strategy

The complexity of the geometry for almost all the façade area requires new solutions in

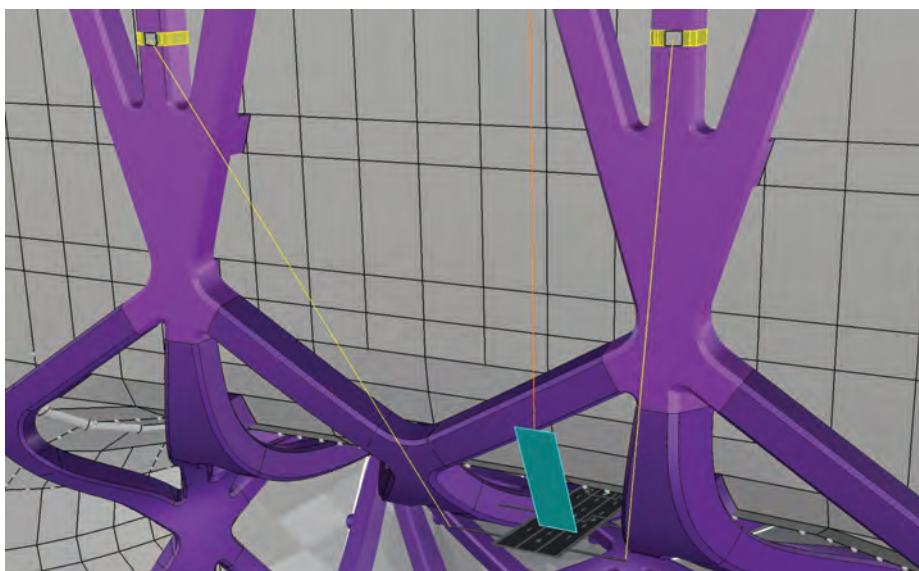


Figure 9. Replacement scheme on underhangs with bespoke temporary accessories (Source: FLY SERVICE Engineering srl)

图9: 使用定制的临时配件在曲面上进行替换 (来源: FLY SERVICE Engineering srl)

terms of general strategy and for the use of project specific devices. The conventional techniques were inapplicable to produce a correct maintenance strategy for COD, hence the solutions involved simple and easy-to-use objects that could ensure the performance required by the project.

The complexity is augmented by requirements to strictly respect Zaha Hadid Architects' articulated architecture.

All solutions were designed with accurate studies of the geometry, of the distances in the various areas between the exoskeleton and the façade, and the necessity to move in these small gaps the panels that are often large and thick.

An extensive and careful analysis of the 3D model has enabled the identification of different areas requiring location specific solutions (Figures 8 & 9).



Figure 8. Replacement scheme on curved underhangs with bespoke temporary accessories (Source: FLY SERVICE Engineering srl)

图8: 使用定制的临时配件在弧面上进行替换 (来源: FLY SERVICE Engineering srl)

为结点大大增加了绳降难度, 也会增加单次下降所需的时间。外骨架的施工同样使用了特殊的转向装置, 在托架内部系统中固定该装置, 不会对外包层产生影响, 也能减少对结构的影响 (图6)。

针对内部中庭, 由于其内部空间呈极其复杂的几何形状, 因此会有一系列的施工困难, 从外立面的自由形态到桥的人工吊顶、电梯竖井以及一系列在更小的区域内遇到的更小的但同样重要的施工问题。所有这些问题都需要与建筑师和参与设计的所有顾问进行协调, 使用绳索技术可以让内部区域形成一个整体。

嵌入锚点的一个很好的案例就是人工吊顶。一系列线性锚点, 沿着打造美学风格的、主要由钻石构成的线条而嵌入。整体布局是与建筑师共同商讨完成的, 以确保获得最有效的效果、减少可见的作业系统 (图7)。使用的颜色与吊顶相同, 锚点也被设计在合适的凹槽中。

## 替换策略

鉴于外立面几乎所有区域的复杂的几何形状, 需要在一般策略和特殊的设备方面提供新的解决方案。常规技术无法为新濠天地何带来适合的维护措施, 因此采用简单易用工具的解决方案, 可以确保项目要求的性能。

严格遵照扎哈·哈迪德建筑事务所设计的铰接式建筑的要求, 增加了维护的复杂程度。

设计的所有解决方案都通过精确分析几何形状、外骨架和外立面之间的几个区域的距离、在这些小的缝隙移动大而厚重的板子的必要性而进行设计。

3D模型广泛仔细的分析可以确定不同区域所需的具体解决方案 (图8、9)。



Figure 10. Bespoke device for sliding the glass on underhangs. The device is an articulated plate in carbon-fiber with sliding Teflon tracks (Source: FLY SERVICE Engineering srl)

图10. 在吊框上滑动玻璃的定制装置。该装置是一个用碳纤维制作的铰接板，在带特氟龙滑轨（来源：FLY SERVICE Engineering srl）

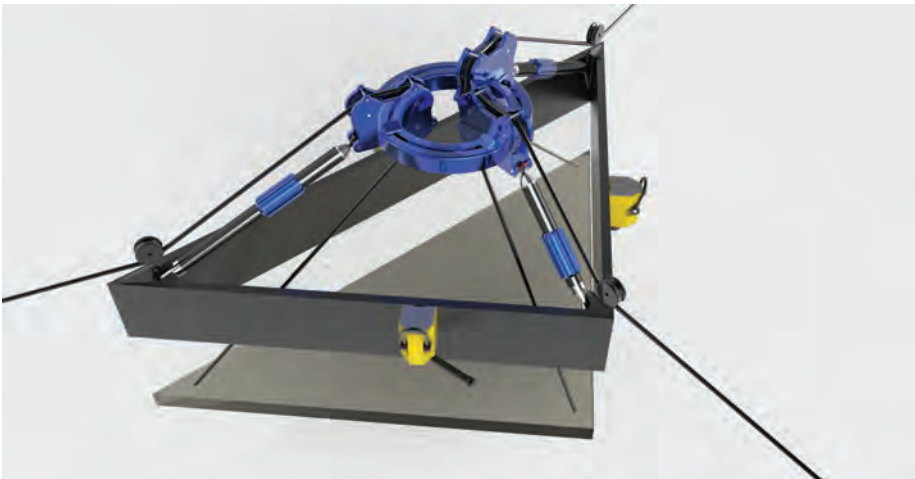


Figure 11. Bespoke lifting system. The device is fixed on the metallic structure of the façade and has adjustable legs (Source: FLY SERVICE Engineering srl)

图11. 定制的升降系统。该装置固定在外立面的金属结构上并且具有可调节的升降臂（来源：FLY SERVICE Engineering srl）

Paths have been strategically devised for the provisioning of replacement slabs in every building area including parts hidden by the exoskeleton. Specific lifting systems have been developed, including one for the summit area and smaller ones for different zones. Bespoke glass handlers have been engineered for each portion of the building: some of these handling devices are connected to the structure of the façade using magnets (Figures 9, 10 & 11).

Other elements of more common use were developed, such as protection systems for the slabs to avoid damage during handling: all devices were developed aiming at a widespread application adaptability.

An example of the difficulties of the design parameters is the fact that using the standard suction cups for handling of the glass proved to be impossible because of the narrow gap between exoskeleton and facade: as a consequence, special pads adhering to the glass with double-sided removable

adhesive were developed, allowing the slab replacement without taking up space. The complex geometry has also required the adoption of lightweight sledges in composite material to move slabs below the exoskeleton. On these sledges the slabs are pulled by winches; to lower the friction, Teflon foils have been applied.

Air force aeronautic technology for carbon fiber lamination was used to reinforce the sledge tracks that showed high stress loads during the finite element modeling analysis.

Every element, tool, accessory and work procedure was revised by an internal panel of rope access supervisors to check safety, comfort and work flow speed.

## Conclusion

The design of a complex façade requires additional expertise for implementing a safe

已经在施工中预先装好了通道，用于替换每一建筑中的厚板，包括被外骨架挡住的部分。同时还特别使用了升降系统，一个用于顶部区域，其他小的升降设备用于其他不同区域。建筑物的各部分都使用了定制玻璃：其中一些处理装置通过使用磁铁与外立面的结构相连（图9-11）。

此外，也开发了更常用的其他元件，比如为避免操作过程中受损而使用的厚板保护系统：所有开发的设备都旨在确保广泛的应用适应性。

很难设计参数的一个例子是由于外骨架和外立面之间的缝隙太小，所以无法使用标准吸盘处理玻璃：因此，特别研制出了一个可附着在玻璃上、双面移动使用的衬垫。有了这个衬垫，就可以更换厚板，而无需占用空间。此外，这种复杂的几何形状也需要使用由复合材料做成的轻质滑板来移动外骨架下方的厚板。通过绞车拉动厚板在滑板上移动，为减少摩擦使用了特氟龙箔。

在有限元建模分析过程中发现滑板的高负载量，因此使用空军航空的碳纤维层压技术来加强滑板的轨道。

每一个元件、工具、配件和工作程序都由绳索系统监督人组成的内部小组负责检查安全性、舒适性及工作流程的速度。

## 结论

设计一个复杂的外立面需要具备额外的专业知识，以实施安全有效的接近和更换策略。从这个意义上说，建筑师和顾问之间进行密切合作非常必要，这样才能在保障安全的同时，尽量减少对建筑美感和相关作业的影响。绳索作业技术被证明是高空作业中非常出色的一个系统，它保障工人最大程度的安全和对建筑设计的最小影响。实践证明它有很好的灵活性，可以用于各种形状的建筑中；此外，如果从最初的设计阶段就与建筑师合作，正确设计，绳索对整体建筑而言是侵入性最小的设备。对于复杂形状的建筑，这一点反映在定制设备的开发上，它可以满足接近外立面和更换部件两方面的极高操作标准。在拥有高品质的工程和创新技术的情况下，绳索作业技术可以有效解决建筑结构和包层维护的问题。



and efficient access and replacement strategy. In this sense, it is crucial to proceed with a strict cooperation between the architects and the consultants to minimize the aesthetic impact with no effect on safety and as little as possible on operational issues. Rope access proves to be an excellent system for working at height with the highest degree of safety for workers and a minimum impact on the design

of the building. It proves to have an excellent flexibility to adapt to any shape of the building, and, if the system is well designed in cooperation with the architect from the first phases of the design process, it results in minimally intrusive equipment. In the cases of complex shapes this is reflected in the development of bespoke devices that achieve very high operational standards for both

access and replacement issues. Rope access techniques can efficiently solve building structure and envelope maintenance issues when supported by high-quality engineering and the deployment of innovative technologies.

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