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| Title: | **Integrating Vertical Cities and Transport Infrastructure** |
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| Subject: | Urban Infrastructure/Transport |
| Keywords: | Density<br>Transportation<br>Urbanization<br>Vertical Urbanism |
| Publication Date: | 2014 |
| Original Publication: | CTBUH 2014 Shanghai Conference Proceedings |
| Paper Type: | 1. Book chapter/Part chapter<br>2. Journal paper<br>3. **Conference proceeding**<br>4. Unpublished conference paper<br>5. Magazine article<br>6. Unpublished |

# Integrating Vertical Cities and Transport Infrastructure

# 整合垂直城市和交通运输基础设施

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**Shonn Mills** has over 20 years of experience in the design and management of large building and transportation infrastructure projects. His international career features experience working on long-span bridges and earthquake engineering, and the design of large public buildings, including airport terminals, metro stations and stadia.

Shonn Mills 在大型建筑和运输基础设施项目的设计和管理方面有超过 20年的经验。在他的国际职业生涯中，他曾参加过大跨度桥梁和地震工程方面的工作，也曾设计过大型公共建筑 (包括机场候机楼、地铁站和体育场)。Shonn 目前关注的是高层建筑以及如何将交通运输交汇处与大型混合用途开发区结合起来。

**Abhijeet** has over 18 years of experience in consulting Civil and Structural Engineering practices, including more than 11 years in the Middle East (predominantly in the UAE). His experience focuses on the field of structural analysis, design and project management of commercial, residential and industrial structures.

Abhijeet Kulkarni在土木和结构工程咨询方面有超过 18 年的经验，其中有 11 年是在中东 (主要在阿联酋) 工作。他的经验集中在商用、民用和工业建筑的结构分析、设计和项目管理领域。这包括针对有影响力的客户和建筑师的许多中高层建筑项目。

**Jamie** works within Ramboll as a Design Engineer, and as part of the design team his analysis and design work contributes directly to project delivery. His experience includes multiple high-rise projects, including seismic design, and international projects in residential, commercial, transport and aviation sectors

Jamie Clay是 Ramboll 的一名设计工程师。作为设计团队的一员，他负责分析和设计工作，对项目的顺利交付起到直接的作用。他曾参加过民用建筑、商用建筑、运输和航空业中的多个高层建筑项目 (包括抗震设计) 和国际项目。


## Abstract

One of the key factors of success in sustainable urbanization is the integration of public transport. This paper explores the challenges and merits of integrating public transport infrastructure with mixed-use high-rise developments at both macro and micro levels . From a planning perspective, locating public transport hubs at the heart of high-rise developments can enrich the social dynamism of the region.

Mshereib Downtown Doha is a ground-breaking project which will regenerate the historical center of Qatar's capital city. Mshereib Downtown Doha Phase 4 (MDDP4) is the showpiece of the QR20 billion development. Msheireb Station, located directly beneath MDDP4, will be the flagship facility and world-class interchange for the Doha Metro. A holistic design approach highlighted the synergy between the two developments, which included an integrated structural philosophy, shared approach to energy use and commercial activity make the combined development greater than the sum of its parts.



**Keywords: Urban Density, Vertical Cities, High-Rise, Transport, Mshereib Downtown Doha, Doha Metro**



## 摘要

可持续城市化获得成功的一个关键因素是公共交通运输的一体化。本文从宏观和微观角度探索了将公共交通运输基础设施与混合用途高层建筑开发区整合在一起的优点和面临的挑战。从规划的角度来看，将公共交通运输中心建立在高层建筑开发区的中心地带可以提高该地区的社会活力。

多哈市中心Msheireb (Msheireb Downtown Doha) 是一个开创性的项目，能使卡塔尔首都的历史中心重新焕发活力。多哈市中心 Msheireb四期项目 (MDDP4) 能很好地展现这个耗资 200 亿卡塔尔里亚尔而建设的开发区的魅力。Msheireb站位于 MDDP4 正下方，它将是多哈地铁的旗舰级场地和世界级的交汇处。这种全面设计的方法强调了两个开发区之间的协同作用 (包括整合的结构理念、共享的能源利用方法及商业活动)，使得结合的开发效果优于其各部分单独效果的总和。



**关键词: 城市密度, 垂直城市, 高层建筑, 交通运输, 多哈市中心 Msheireb, 多哈地铁**


## Introduction

As the world transitions from the countryside to cities, it is projected that 69% of the global population will live in urban areas by 2050 (United Nations, 2009). While this presents a challenge to existing city infrastructure and planning regulations, it also drives the agenda for sustainable growth through greater urban density, taller buildings and further investment in public transport.

The movement of goods, services and data is the lifeblood of a city and a strong public transport backbone is essential in today's economy. As cities increase in size, the relationship between transport and commercial activity becomes more vital. To this end, it is critical that high-density areas with the tallest buildings coincide with a city's public transport hubs.

Solid planning has the potential to reorder a city, create new neighborhoods and to kick-

## 简介

随着世界从乡村过渡到城市，预测在2050年之前世界人口的69%将住在城市区域 (联合国，2009 年)。这不仅对现有城市基础设施和规划规程提出了挑战，也推动了针对通过提高城市密度、建筑高度和向公共交通运输投资来实现可持续增长的议程进展。

商品、服务和数据的流动是城市的生命线，而强大的公共交通运输网络对当今经济来说至关重要。随着城市规模的扩大，交通运输和商业活动之间的关系也变得越来越重要。因此，必须要让拥有最高建筑的高密度区域与城市的公共交通运输中心重合在一起。

进行可靠的规划将有可能重新布置城市的布局，创建新居住区并加速城市再生的进程。为了达到这一目标，有关各方必须在公共基础设施和商业发展问题方面进行协作。为了实现未来增长并提高城市密度，这种原理应超越共享财产所有权的范围。这种新的一体化原理应该探索出一种一体

start urban regeneration. In order for this to happen, involved parties must work in cooperation on public infrastructure and commercial development issues. To the future growth and urban density, this philosophy should go beyond shared property ownership. The new integrated philosophy should explore an integrated commercial model, and capitalize on the opportunities of shared building systems (energy and data), shared security and life safety strategies.

This paper presents this integration on two levels, firstly macro integration which encompasses city level planning and locating high density developments adjacent to transport hubs. This helps to increase efficiency to users, reduces automotive transport requirements and promotes urban life. Secondly, integration can occur on the micro level. This occurs when integrating specific projects, and involves integration of structural elements and service strategies. This form of integration can have significant savings in construction material quantities, energy usage and spatial benefits. An elevated degree of coordination, design and planning is required at the micro level integration.

The themes of macro integration are discussed throughout this paper, while examples of micro integration are explored via the case study of Msheireb Downtown Doha Phase 4 (MDDP4) and Msheireb Station projects.

## Precedence

The integration of public transport infrastructure and commercial development is not a new concept. The following are a few historical case studies that highlight the importance of an integrated planning approach.

### London & Canary Wharf

Canary Wharf is today a major business and financial district located in the West India Docks in East London. It is home to around 14 million square feet of office and retail space, and is home of the headquarters of major professional services firms and banks (MacGregor, Reuters, 2007).

Construction of the first towers was completed in 1991, including One Canada Square, the then-tallest tower in the UK. Although the towers became a symbol for the Docklands' regeneration, completion was ill-timed, as it coincided with a collapse in the London commercial property market. It proved a disaster for the project's owner, Olympia and York Canary Wharf Limited, forcing them to file for bankruptcy in 1992. As the market somewhat recovered during the 90s, a critical event in the region's progress was the London Underground's Jubilee line extension with stations opening in 1999. This was a much-delayed project, also due to the recession, but its completion was driven by the government, who wanted the line open before the millennium – a very different cause than the woes of Canary Wharf. From a developer's perspective, this highlights the importance of integrated planning.

Today, over 100,000 people (Lazarus, 2014) travel to Canary Wharf to work in one of the regions many towers. The area's transport credentials have been further-improved since the opening of the Jubilee line (Figure 1). The region is also connected to the Docklands Light Railway (DLR), an automated light metro system which predominantly serves the Docklands area in east and southeast London. Both the Jubilee and DLR lines have been extended, enhancing links to the district. In 2010, nearly 17 million people entered and exited the station at Canary Wharf, a figure that was

化的商业模式，还要充分利用共享建筑系统 (能源和数据) 、共享安全和生命安全策略所带来的机遇。

本文从两方面阐述了这种一体化。第一方面是宏观一体化，包括城市级规划以及将高密度开发区建立在交通运输中心的旁边。这有助于提高用户的效率，降低汽车交通运输要求和提升城市生活水平。第二方面是微观一体化。这是关于对具体项目的整合，包括整合结构元素和服务策略。这种形式的一体化能极大地节省建筑材料用量、能源用量和空间占用量。进行微观层面的一体化需要更高程度的协作、设计和规划。

本文着重讨论宏观一体化的主题，而微观一体化的例子则通过多哈市中心 Msheireb四期 (MDDP4) 和 Msheireb站项目进行探索。

## 实例

公共交通运输基础设施和商业开发区一体化并不是一个新概念。以下是一些强调一体化规划方法的历史案例研究。

### 伦敦金丝雀码头

今天的金丝雀码头是一个大型商业和金融区，位于伦敦东部的西印度码头。这里有大约1,400万平方英尺的办公和零售区域，也是主要专业服务公司和银行的总部所在地。(马基高，路透社，2007 年)

首批高楼的建设是在1991年完成的，包括第一加拿大广场，这是当时英国最高的楼。尽管这些高楼成为了伦敦码头区振兴的象征，但其竣工时机很差，因为当时正好伦敦商业地产市场出现了价格暴跌。这对项目所有者奥林匹亚约克金丝雀码头有限公司来说是一场灾难，迫使该公司在1992年提交了破产申请。该市场在90 年代出现了些许复苏，而在该地区取得进展的过程中有一个至关重要的事件，那就是伦敦地铁的银禧延长线 (包括站点) 在1999年开通了。此项目延期了很久，原因也是经济衰退。但其竣工是由政府推动完成的，政府想让这条线在千禧年之前开通，这与金丝雀码头的不幸相比是完全不同的原因。从开发者的观点来看，这突出了一体化规划的重要性。

今天，超过100,000 人 (Lazarus，2014) 前往金丝雀码头，在该区域众多高楼中的某一栋中工作。自银禧线开通以来，该区域的交通运输能力得到了进一步提升 (图 1) 。该区域还与伦敦码头区轻轨 (DLR) 相连，此自动轻便地铁系统主要为伦敦东部和东南部的码头区提供服务。银禧和DLR 线路都已被延长，这增强了其他地区与此地区的联系。在2010 年，有将近1,700 万人进出金丝雀码头的站点。此数据是单独从DLR站点记录的 (TFL，2011 年) 。该终点站当前很受城市规划者的重视，因此被纳入了伦敦耗资巨大的Crossrail交通运输项目中。Crossrail 是伦敦交通运输基础设施中重

Figure 1. Canary Wharf, London (Source: Xaxor)
图 1. 伦敦金丝雀码头 (来源: Xaxor)

recorded from the DLR point alone (TFL, 2011). The terminal is currently viewed by city planners as being so critical that it is being incorporated into London's ambitious Crossrail transportation project. Crossrail is vital new development in London's transport infrastructure, consisting of a 118 km rail line running east-to-west, connecting parts of Buckinghamshire and Berkshire to Essex via central London. The new Canary Wharf station itself is being built in a partnership between Canary Wharf Contractors and Crossrail.

### Kowloon Station, Hong Kong

An example of a successful approach to the integrated planning of high-rise developments and transport is the Kowloon Station masterplan in Hong Kong (Figure 2). The development, known as Union Square, was based on the concept of creating a true urban hub. Apartments and offices are housed in a number of towers which sit directly above Kowloon Station, a major transport hub with both metro and airport rail connections. The towers are then linked together by a podium which provides air-conditioned underground retail space, and parks and gardens at street level. This is a great showcase of envisioning a "vertical city" during planning, with the development offering convenience, accessibility and efficiency to residents and workers.

In addition to this, a great deal of flexibility in the masterplan project was required during planning and design. During the station's design and construction, the above-grade masterplan underwent five cycles of design adjustment. This was largely driven by airport height restrictions of the towers and the underlying driving force of Hong Kong's economy on the development. But while this number of iterations may not be typical, it highlights the need for an integrated approach to planning. Success of the masterplan here was only enabled by careful consideration of the needs of the transit hub, therefore fulfilling the concept goal of turning the area in to a transport "super city."

## Case Study – Mshereib Downtown Doha and Msheireb Station Projects

### Project Background

Msheireb Downtown Doha is a flagship project which will regenerate and preserve the old commercial heart of Doha. Covering 31 hectares (Figure 3), the project will create a new community with a focus on sustainability and cohesion. The developer behind the project, Msheireb Properties, states that "on completion, Msheireb will be an iconic landmark in Doha – a globally recognizable community where people live, work and thrive." Currently under construction, (Figure 4) the project also brings admirable sustainability credentials; with all buildings

Figure 2. Kowloon Station, Hong Kong (Source: Wikipedia Commons)
图 2 香港九龙站 (来源: Wikipedia Commons)

要的新开发项目，由长118千米、走向由东至西的轨道构成，通过伦敦中部将白金汉郡和伯克郡与埃塞克斯郡连接起来。新金丝雀码头站正在由金丝雀承包商和Crossrail进行合作建设。

### 香港九龙站

香港九龙站总体规划 (图 2) 是进行高层建筑开发区和交通一体化规划的成功典范。基于创建一个真正的城市中心的理念，联合广场开发区得以建成。九龙站是一个同时与地铁和机场具有轨道连接的大型交通中心。该站的上面坐落着许多高楼，高楼内有公寓和办公室。这些高楼有一个平台连接起来，平台上提供了带空调的地铁零售区以及街道级的公园和花园。这是一个非常好的示例: 在规划时设想了一个"垂直城市"，要在其中建造一个开发区，为居民和劳动者提供方便，让他们能轻松到达许多地方，并提高他们的生活和工作效率。

除此之外，在规划和设计过程中还需要对总体规划项目进行大量的灵活处理。在该站的设计和建造过程中，这个复杂的总体规划经历了五次设计调整。这主要是由机场高楼高度限制以及香港经济对此开发区的潜在推动力所推动的。尽管这种重复次数可能不是很典型，但它突出了采用一体化方法进行规划的需要。这个总体规划的成功完全依赖于对交通运输中心需求的细致考虑，从而完成了将此区域变为交通运输"超级城市"的概念性目标。

## 案例研究 – 多哈市中心 Msheireb和Msheireb站项目

### 项目背景

多哈市中心 Msheireb是将振兴并保存多哈老商业中心的旗舰级项目。该项目占地面积31公顷 (图 3)，它将以可持续性和凝聚性


Figure 3. Msheireb Downtown Doha (Source: HOK Architects)
图 3. 多哈市中心Msheireb (来源: HOK建筑师事务所)

Figure 4. Msheireb Under Construction (Source: Msheireb Properties)
图 4. 建设中的Msheireb (来源: Msheireb地产)

targeting Gold level LEED certification, making it the largest collection of such buildings in the world upon completion. "The entire project features sustainable design that consumes fewer resources, generates less waste, costs less to operate, and achieves a reduced carbon footprint," says Msheireb Properties of the project (Msheireb Properties, 2013).

Phase 4 of the project (MDDP4), which sits at the southeast corner of the site, is a mixed-use development that includes 12 towers up to 25 stories each. It will provide commercial office space, medical office facilities, residential apartments, a hotel, and a six-level underground parking lot.

Msheireb Station Doha Metro is an-all new rapid transit system for the Qatar capital. With over 200 km of rail over four lines, and serving 100 stations, the metro will also be an integral part of the wider Qatar Rail network (Qatar Rail, 2012). At the heart of the network lies Msheireb station (see Figure 5), a significant interchange between three of the four lines (red, green and gold), which will provide a world-class transportation system set to open in advance of the 2022 world cup. It is to be the largest hub on the network, which will serve 470,000 passengers daily.

The combination of the station and the mixed-use development above will create a significant new regional destination for residents and visitors long into the future.

**Site Description**

MDDP4 consists of four groups, or "blocks", of buildings called W, X, Y and Z-blocks. The W-block is situated on the northwest corner of the site and provides office space over two buildings with a shared podium. X-block is home to three residential buildings and a hotel tower. Y-block consists of four medical office towers and is situated on the northeast corner. To the south of the site, Z-block, consisting of four main buildings, provides additional office space. Retail spaces are provided throughout the side at the lower levels. Building heights are typically 8-12 stories, with the exception of Z-block, which includes 23 and 17-storytowers.

Msheireb Station is the intersection of three main lines: the golden line, which sits to the south of the MDDP4 boundary in Mshereib Street; the red/green station which lies beneath the south/east portion of the site; and the red/green switch box which lies beneath the northeast quarter of the site (partially in Al Diwan Street).


Figure 5. Doha Metro Map (Source: Qatar Rail)
图 5. 多哈地铁地图 (来源: 卡塔尔轨道)

为中心来创建一个新社区。该项目的开发商Msheireb地产表示: "该项目完成后，Msheireb 将成为多哈的标志性地标，成为受世界认可的社区，人们可以在这里生活、工作并创造辉煌。"该项目目前正处于施工阶段 (图4)，它还带来了令人赞赏的可持续性资历，其所有建筑都以获得 Gold level LEED 认证为目标而建造，这将使其在竣工后成为世界上拥有此类建筑最多的建筑群。"这个项目的各个部分都采用了可持续设计，能降低资源消耗、垃圾产生量、运营成本和碳排放量。"负责该项目的 Msheireb地产表示 (Msheireb地产，2013年) 。

该项目的第四期 (MDDP4) 位于项目地点的东南角，它是一个混合用途开发区，其中有 12 栋高楼，每栋最多有 25 层。它将提供商业办公区域、医疗办公设施、住宅公寓、一家酒店以及一个六层的地下停车场。

Msheireb站多哈地铁是卡塔尔首都的一个全新的快速交通运输系统。该地铁共有四条线，轨道全长超过200千米，为100个站点提供服务。该地铁将成为更大的卡塔尔轨道网不可或缺的一部分 (卡塔尔轨道，2012年) 。该轨道网的中心是 Msheireb站 (参见图5) ，这是四条线中三条 (红、绿、金) 的重要交汇点，它将提供一个世界级的交通运输系统，这将在 2022 年世界杯开始前开通。它将成为轨道网中最大的中心，每天将为470,000名乘客提供服务。

这种站点和混合用途开发区的组合将为居民和游客创建一个重要的新区域性目的地，并且很长时间内都会如此。

**项目地点介绍**

MDDP4 由四组或四个"区"的建筑组成，分别为W、X、Y和Z区。W区位于项目地点的西北角，拥有两栋楼房和一个共享的平台，用于提供办公区域。X区拥有三栋住宅楼和一栋酒店高楼。Y区由四栋医疗办公高楼组成，位于东北角。Z区位于项目地点的南部，由四栋主楼组成，用于提供额外的办公区域。整个项目地点的所有楼房低层都用于提供零售区域。楼房高度一般为8至12层，只有Z区例外，有23层和17层的楼房。

Msheireb 站是三条主线的交汇点: 金线: 位于Msheireb街，MDDP4边界的南部; 红/绿站: 位于项目地点东/南部的下面; 红/绿交换处外壳: 位于项目地点东北部 (部分在Al Diwan街) 的下面。

该项目早期的铁路线形开始是计划将Msheireb站建在MDDP4的旁边，完全位于Al Diwan街和Msheireb街的公共事业用地内。它还包括一个连接到项目地点的较低层级的步行道。但是，Al Diwan街的限制要求对通过MDDP4地产的地铁线形进行重新调整 (参见图 6) 。这次对车站外壳的重新调整极大地减少了MDDP4地下室的可用区域。

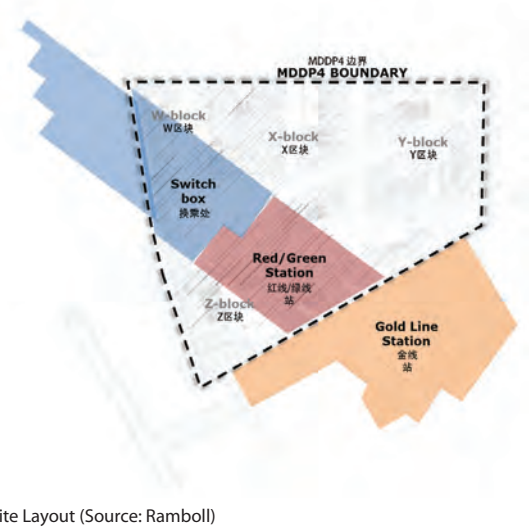


Figure 6. Site Layout (Source: Ramboll)
图 6. 项目地点布局 (来源: Ramboll)

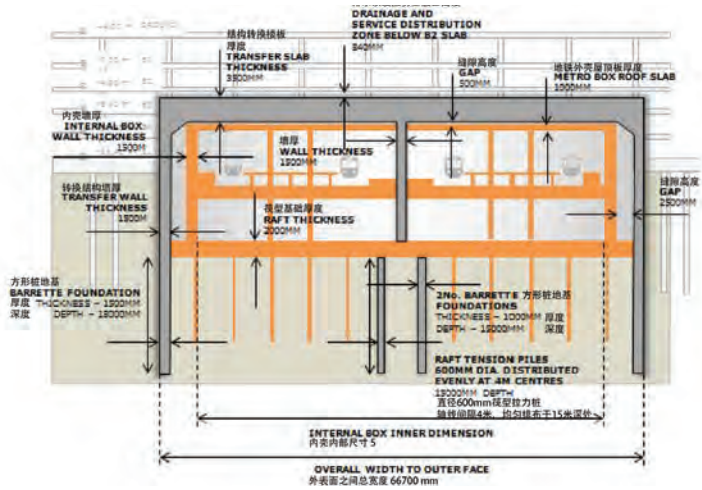


Figure 7a. Isolated Structure. (Source: Ramboll)
图 7a. 独立的结构 (来源: Ramboll)

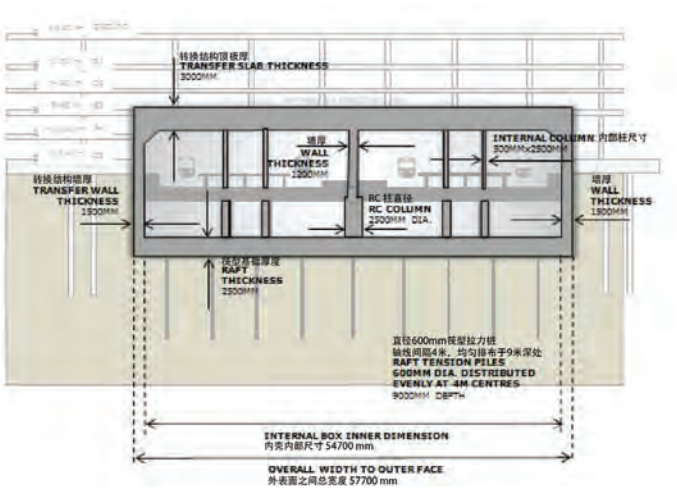


Figure 7b. Integrated Structure. (Source: Ramboll)
图 7b. 一体化结构 (来源: Ramboll)

The early metro alignment for the projects originally had the Msheireb Station located adjacent to MDDP4, fully within the public right-of-way of Al Diwan Street and Mshereib Streets. It would also include a lower-level pedestrian connection to the site. However, constraints on Al Diwan Street required a realignment of the metro alignment through the MDDP4 property (see Figure 6). This realignment of the station box significantly reduced the area available for the MDDP4 basement.

### Integration

Subsequent to the realignment the projects initially remained separate, both in terms of design and construction, largely meant to simplify the interface between the two projects. This early approach resulted in an isolated metro box, separated from MDDP4 by a large transfer structure to support the multiple towers sitting directly above the station (see Figure 7a). During the design process, however, it was noted that there were a number of potential benefits which could be unlocked via integration.

### Future Planning

With the incorporation of Msheireb station beneath MDDP4, an element of future-proof planning was introduced that was not previously required. With a design life of 120 years, Msheireb station could potentially outlive the above-grade development, with a design life of 60 years. Therefore, it was required that both the metro and MDDP4 designs allowed for future development of the site, protecting both the investment of Msheireb Properties, and the integrity of the metro structure.

A rationalized approach was agreed upon where the MDDP4 site was split into three zones, specifying maximum building heights of 25, 18, and 12 stories respectively for each zone (Figure 8). This "flexible load case" drives many areas of the structural design of the project, including the transfer structure, lateral stability and differential settlement. By adopting this approach, however, a great deal of value is added by allowing future redevelopment of the site, without impacting on the metro structure. What's more, by considering the interests of all parties, this approach to planning improves the sustainability of the development in the long-term.

### Structure

The initial structural solution for the project involved separation of the metro station and MDDP4 basement, with box-in-box structures. The metro station-box was to be designed to resist lateral and gravity earth pressures, assuming MDDP4 would be demolished within the metro's design life. This preliminary design included 1.5m retaining walls and a 1.0m-thick roof slab. Separation between Msheireb station and MDDP4 was then accomplished by a long-span transfer structure over the metro structure.

### 一体化

进行重新调整后，该项目最初在设计和建设方面仍为分离的，这很大程度上说明要简化两个项目间的衔接。该早期方法导致出现了隔离的地铁外壳，通过一个大型转移结构域MMDDP4分离开来，从而支持位于站点正上方的多个高楼 (参见图7a) 。但是在设计过程中，人们注意到有一些潜在的好处，通过一体化可以挖掘出这些好处。

### 未来计划

在MDDP4下面建设Msheireb站 (属于不会过时的规划要点) 的未来规划得到了采用，而这在之前并没有相关要求。Msheireb站的设计寿命为120年，这让其有可能比高级开发区 (设计寿命为60年) 具有更长的使用寿命。因此要求地铁和MDDP4设计允许在未来对项目地点进行开发，从而保护Msheireb地产的投资和地铁结构的完整性。

一个经过合理化的方法得到了批准，该方法指定了MDDP4地点应如何分为三个区，还指定了每个区域的最大楼层高度分别为25、18和12 (图8) 。这个"灵活的荷载工况"推动了此项目结构设计的许多方面的发展，包括转移结构、横向稳定性和不均匀沉降。但是通过采用此方法，允许在未来对项目现场进行重新开发可带来很多附加价值，同时不会对地铁结构造成影响。此外，通过考虑各方的利益，该规划方法能提升开发区的长期可持续性。

### 结构

若要对该项目的初始结构解决方案进行精心安排，需要利用壳中壳结构将地铁站和MDDP4地下室分离开来。将要设计出能抵抗横向和重力方向的土压力的地铁站外壳，这说明在地铁的设计寿命

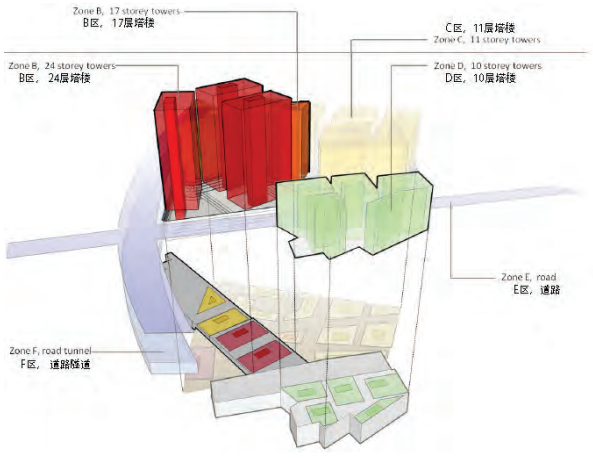


Figure 8. Future MDDP4 redevelopment zones by building height. (Source: Ramboll)
图 8. 由建筑高度划分的未来MDDP4再开发区域 (来源: Ramboll)

This approach provided a simplified interface, and while the two projects shared the same site, they could be constructed and maintained independently. The program of works for each project could also be kept largely independent under this arrangement. Additionally, redevelopment of MDDP4 would be made possible with minimal impact on the metro structure, easing the process for redevelopment in the future. While this approach provided many advantages it also had a significant impact on the construction cost, schedule and overall complexity of the project.

A key design driver was to minimize adverse impacts to MDDP4, given the large amount of MDDP4 spatial planning already being completed prior to co-alignment with Msheireb station. From a fixed elevation of the rail tracks, to usable MDDP4 space there was a build-up of clear height above rails, metro-box roof, separation distance and MDDP4 transfer structure. The latter was subject to onerous conditions, with clear spans of over 60m and with the necessity to cater for future flexibility loading. In order to try to reclaim a level of MDDP4 basement space, there was great incentive to minimizing this build-up thickness and reclaim a level of basement.

In order to facilitate an integrated design, the integrated structure was designed to accommodate redevelopment and demolition of the MDDP4 towers within the station's operating life. For example, the transfer structure was designed for earth pressures as well as MDDP4 building gravity loads and the integrated walls were designed for lateral earth and hydrostatic pressures. Foundations were designed for worst-case uplift and gravity conditions. In addition to this, integrated movement joint and stability philosophies were developed, with integrated 3D stability analysis being carried out. Finally, site-wide differential settlement analysis was cross-verified using three separate analysis techniques to ensure the metro structure's performance under future load scenarios (including net uplift and gravity loading).

By adopting an integrated approach, it was possible to combine the metro roof slab and MDDP4 transfer structure. This not only reduced the spatial build-up above metro rail level, but also introduced additional points of support for the transfer structure. It allowed the depth to be significantly reduced (see Figure 7b). In addition, the vertical structure (MDDP4 and metro-box walls) could also be integrated, leading to a significant material savings. Eliminating redundant structural elements through integration reduced concrete quantities by over 20,000m$^3$, For perspective, this is greater than the total superstructure concrete volume of the tallest MDDP4 tower, Z01a.

The integrated approach allowed an additional level of parking to be saved over the metro station footprint (see Figure 9) and saved approximately 5,500 tons of $CO_2$ in embodied energy of concrete.

**Energy and Waste**

The original philosophy for the projects was completely separate energy and waste systems. As with the original structural philosophy, this approach provided a simplified interface and allowed the project to be constructed and maintained independently. After the integration approach for the structure was agreed, the potential synergies between a shared approach to energy and waste were studied. The MDDP4 project is being served by district energy systems, which provide for the majority of the sites buildings services requirements. The study involved expanding the MDDP4 system to include capacity to serve the station. This system would be designed to maintain energy supply throughout the station's design life. Sufficient robustness would be provided to ensure the system remains fully operational during future redevelopment of the MDDP4 site, as part of the development agreement.

内要拆除 MDDP4。该初步设计包括1.5米的挡土墙和一个1.0米厚的顶板。之后Msheireb站和MDDP4便由地铁结构上的一个大跨度**的转移结构分隔开了。**

此方法提供了一个简化的接合点，同时这两个项目具有相同的地点，所以可以独立地对它们进行建造和维护。在此种安排下，每个项目的工作计划都可以在很大程度上相互独立。此外还可以对MDDP4进行重新开发，同时对地铁结构造成的影响最小，这可以降低将来进行重新开发的难度。除了有许多优势外，此方法还对项目的建造成本、日程安排和整体复杂度有着深远的影响。

因为大量的MDDP4空间规划已在对Msheireb站进行联合调整前完成，所以一个关键的设计推动因素是尽量减小对MDDP4的不利影响。在平行于轨道的剖面上可以看出，从轨道、地铁外壳顶、分隔距离到MDDP4转移结构的净空高度不断增加。后者面临着艰巨的条件，具有超过60米的净跨度，需要满足未来的灵活性负载需求。为了尽力开发利用MDDP4地下室区域的一层，尽量减小累积厚度并改造利用一层地下室很有必要。

为了促进一体化设计，人们设计了一体化结构来帮助在车站的运营寿命内对MDDP4高楼进行重新开发和拆除。例如，人们设计了转移结构来应对土压力和MDDP4建筑重力负载，并设计了一体化墙壁来应对横向土压力和液体静压力。地基是针对最差的隆起和重力条件而设计的。除此之外还开发了一体化的移动结合处和稳定性机制，进行了一体化的三维稳定性分析。最后利用了三种独立的分析技术对整个项目地点的不均匀沉降分析进行了交叉确认，从而确保地铁结构在将来承受负载 (包括纯隆起和重力负载) 时能发挥正常性能。

通过采用一体化方法可以使地铁顶板和MDDP4转移结构结合起来。这不仅减少了地铁轨道层面上的空间累积，也为支撑转移结构增加了额外的支撑点。这让厚度可以极大地减小 (参见图7b) 。此外也可以将垂直结构 (MDDP4和地铁外壳墙) 一体化，这可以极大地节省材料。通过一体化去除多余的结构元素让混凝土的用量减少了超过20,000立方米。换个角度来说，这比最高的MDDP4高楼Z01a的全部上层构造所用的混凝土量还要多。

此一体化方法能在地铁站占用空间量中节省出一层额外的停车场 (参见图9) ，并能使水泥中二氧化碳隐含量减少约5,500吨。

**能源和垃圾**

该项目的初始设计思路是完全独立的供能系统和垃圾处理系统。对于初始的结构设计思路来说，该方法提供了一个简化的接合点，并让人们能独立地对项目进行建造和维护。在结构一体化方法获得批准后，对共享能源和垃圾系统的方案的潜在协同作用进行了研究。地区能源系统对MDDP4项目进行供能，该系统为对项目地点附近的大多数建筑供能。这项研究包括扩展MDDP4系统，

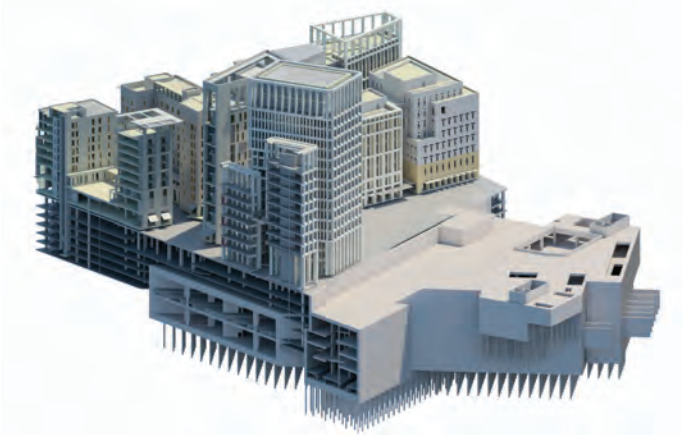

Figure 9. Msheireb Integrated Section. (Source: Ramboll)
图 9. Msheireb一体化地段 (来源: Ramboll)

The issues of maintenance under operation, however, limit the integration of these systems. Full integration, if possible, would lead to further opportunities. For example, differing patterns of demand will exist in the MDDP4 buildings and the metro. Therefore, energy systems could be optimized to minimize energy consumption, whereby peaks in residential systems (early morning and late evening) are counterbalanced by peaks in retail spaces within the metro space (afternoon).

The initial service strategy for heat rejection included air-cooled chillers located just below ground level and covered with grating to allow ventilation. This results in a large area at ground level of which is sterilized against future development. One of the integrated design options included incorporating the metro chillers at roof level of the adjacent towers. A system replacement strategy was also drafted in order to ensure the system could be relocated during the station's design life as towers are constructed and demolished. This approach allowed the use of more efficient water cooling towers, providing a significant reduction in the overall plant area build as well as the obvious benefit of freeing up valuable land plot adjacent to the site.

**Fire Life Safety**

The original philosophy for MDDP4 and the station both included separate and independent strategies for Fire Life Safety and Security. The station realignment required a detailed review of these strategies and meant there would be an overlap with several life safety systems, including alarm, surveillance and public address systems. In addition, several related station elements such as means of escape and smoke control shafts would now pass through the MDDP4 development (see Figure 10). While these elements take up valuable basement space the team explored the possibilities and benefits of integrating the means of escape for elements of the public and private development. If successful this would mean a significant reduction in space required and potentially an overall improvement in public safety.

## The Case for Integrated Planning

**Macro Level**

The advantages of integrated planning between high-rise redevelopments and transport networks are numerous and powerful. Perhaps most importantly, an integrated approach to planning enhances the user experience of our buildings, by collecting amenities, offices and residential spaces within easy transport hubs. It brings convenience and efficiency for residents and visitors.

With the increasing interest in "vertical city" concepts, even greater importance is placed upon transport links to enable flow between each vertical community. This is showcased by examples such as the location of London's Shard, directly adjacent to London Bridge station, which was heavily influenced by a UK government whitepaper encouraging development of tall buildings at major transport hubs.

Efficient public transit systems also reduce the demand on automotive infrastructure, while placing hubs adjacent to vertical developments enhances this benefit.

使其有能力为站点提供服务。设计该系统是为了在站点的整个设计寿命内维持能源供应。开发协议规定，要让系统具有足够的鲁棒性以使其能在将来的MDDP4项目地点重新开发期间正常运行。

但是要在运行中进行维护，这一问题使这些系统的一体化受到了限制。如果有可能达到完全的一体化的话，将会带来更多机遇。例如MDDP4建筑和地铁中将存在不同类型的需求。因此可以优化能源系统以尽量减少能源消耗，从而让住宅系统的能耗高峰 (早晨和夜晚) 可以被地铁区域内的零售区域的能耗高峰 (下午) 所抵消。

针对排热的初始服务策略包括位于地下的气冷式制冷器，该制冷器上覆盖有格栅以便于通风。这使得地面上出现了一大片区域，该区域被留出以用于将来的开发。有一种一体化设计是要将地铁制冷器安装在临近高楼的顶部。同时还拟定了一个系统更换策略以确保能在站点的设计寿命内对高楼进行建造和拆除时对系统进行转移。此方法让更高效的冷却水塔可以得到利用，从而能极大地减少整个设施的建造面积，并能空出项目地点旁边宝贵的地块。

**消防与生命安全**

MDDP4和站点的初始设计思路都包含了针对消防与生命安全的相互独立策略。若要对站点进行重新调整，需要对这些策略进行细致的审查，这还意味着一些生命安全系统 (包括报警系统、监控系统和公用地址系统) 将出现重叠。此外，一些相关的站点元素 (例如逃生途径和烟雾控制井) 现在将通过MDDP4开发区 (参见图10) 。尽管这些元素占用了宝贵的地下室空间，但项目团队研究了针对公用和私人开发区元素来整合逃生途径的可能性和好处。如果成功的话，这将能极大地减少需要的空间，并可能会在整体上改善公共安全状况。

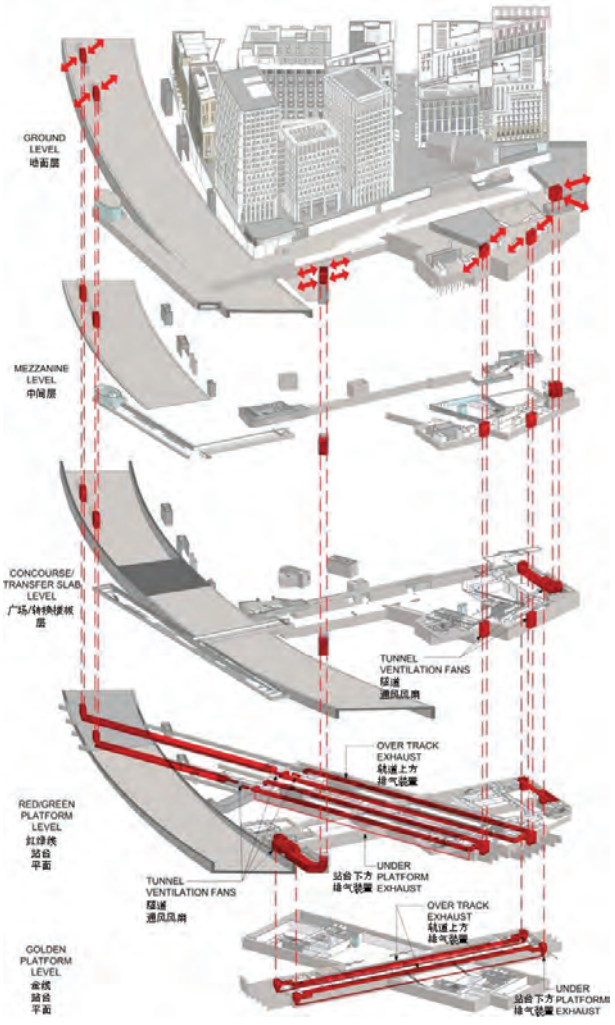


Figure 10. Integrated Building Systems. (Source: Ramboll)
图 10. 一体化建筑系统 (来源: Ramboll)

**Micro Level**

On the micro level integration can benefit our designs in every engineering discipline. Structural integration can lead to optimization opportunities and reduce construction material quantities. Savings to construction programs may also result from this integration process. Energy and waste strategies may be combined, reducing operational energy loads. The scope for energy efficient concepts, such as site-wide natural ventilation, district heating/cooling, and combined heat and power can also be improved. The advantages are also compounded; spatial benefits resulting from reduced structure/service areas may also result as part of integrated processes, improving the efficiency of our spaces. In addition to the examples in the case study, further integration is possible in our projects. For example, vertical transport systems may be integrated.

In turn, these factors are advantageous from a developer's perspective. Capital and operational costs are minimized and net efficiencies are increased. Furthermore, by planning for future redevelopment of our cities, investments can be maximized and protected as land use changes. This is particularly important when considering the long design lives of transport infrastructure.

There are issues to be considered with integration, however. Differing design lives must be appreciated, with engineering designs taking into account these redevelopment scenarios. Design drivers may also differ between varying components of an integrated design, and contractual issues of the parties involved must be taken into account during design phases, construction, and the operation of all developments.

When properly planned for and executed, integration provides many opportunities to enhance user experience, improving sustainability credentials and contributing to the efficient operation of cities.

## Conclusions

The following list presents the merits and issues of integrating transport and high-rise developments.

- Provides opportunities to enhance user experience and convenience of amenities.
- Provides improvements in the efficiency of spaces.
- Integrated planning can help to better fulfill the aims of government/local authorities.
- Increased opportunities for developers.
- Encourages foresight into future redevelopment of project sites.
- Wide-ranging sustainability merits, including reduced operational energy usage and reduced embodied energy.
- Differing design lives must be taken into consideration.
- Contractual issues require close consideration throughout planning and design phases.

## 一体化规划案例

**宏观层面**

对高层建筑重新开发和交通运输网络进行一体化规划的好处数不胜数且效益明显。利用一体化规划方法可以通过将生活设施、办公室和住宅区集成在便利的交通运输中心中，提高用户使用建筑的体验——这一点可能是最重要的。它能为居民和游客带来方便和效率。

随着人们对"垂直城市"概念的关注度越来越高，交通运输连接也受到更多的重视以实现各个垂直社区之间的流通。这一点在伦敦碎片大厦所在的位置得到了很好的体现——该大厦紧靠伦敦大桥站，英国政府关于鼓励在大型交通运输中心建设高层建筑的白皮书对此大厦起到了很大的影响。

高效的公共交通运输系统同时还降低了对汽车基础设施的需求，而将交通运输中心建设在垂直开发区的旁边则增强了这一优势。

**微观层面**

在微观层面上，一体化能在所有的工程规范方面让我们的设计受益。结构一体化能带来最佳机遇并减少建造材料用量。此一体化过程还可能降低建设计划的成本。可能会合并能源和垃圾策略，从而减少运营能源负载。这还可以改进能源效率概念范畴内的各个方面，例如整个项目地点的自然通风、地区供暖/制冷以及热电联产。优势也是交织在一起的: 减少结构/服务区域带来的空间优势也可能会提高我们对空间的利用率，这是一体化过程的一部分。除了此案例研究中的例子外，我们的项目还可以实现更高程度的一体化，例如: 可以将垂直交通运输系统加入一体化范围。

相应地，这些因素从开发商的角度来看是非常有优势的。这会使资本和运营成本降到最低并提高净效率。此外，通过规划在未来对我们的城市进行重新调整，我们就可以在土地使用发生变化时充分利用并保护投资。这在考虑交通运输基础设施的长设计寿命时显得尤为重要。

但是也要考虑一体化的一些问题。必须重视不同的设计寿命，因为工程设计考虑了这新些重新调整的情况。一体化设计的不同部分可能会有不同的设计推动因素，同时必须在所有开发区的设计阶段、建造和运行期间考虑有关各方的契约问题。

如果正确规划并实施了一体化，这将带来很多机遇来提高用户体验、提升可持续性资历并促进城市的高效运营。

## 结论

下表列出了交通运输和高层建筑开发区一体化的优点和问题。

- 为提升用户体验和生活设施的便利性带来了可能。
- 提升了空间的利用率。
- 一体化规划有助于更好地实现政府/地方部门的目标。
- 为开发商带来更多的机遇。
- 激励对在未来对项目地点进行重新调整进行设想。
- 各种各样的可持续性优点，包括降低运营所消耗的能量以及生产所消耗的能量。
- 必须考虑不同的设计寿命。
- 需要在整个的规划和设计阶段对合同相关问题进行密切的关注。

## Acknowledgements

The authors would like to acknowledge Msheireb Properties, Qatar Rail and the full client and consultant team for the collaborative and constructive approach that will help ensure the success of the Msheireb Downtown Doha and the Doha Metro.

## 鸣谢

本文作者希望感谢Msheireb地产、卡塔尔轨道和所有的客户和咨询团队所提供的合作性和建设性方法，该方法将有助于确保多哈市中心Msheireb和多哈地铁的成功建成。

References/参考文献

Lazarus, D. (2014) **Canary Wharf Boss Sees Future in Creative Campus** [Online], Available: http://www.efinancialnews.com/story/2014-03-12/future-of-canary-wharf-sir-george-iacobescu-tech-education?ea9c8a2de0ee111045601ab04d673622 [12 Mar 2014]

MacGregor, L., Reuters (2007) , **Higher Occupancy Lifts Canary Wharf's Songbird** [Online], Available: http://uk.reuters.com/article/2007/03/22/uk-songbird-results-idUKL2253602220070322 [22 Mar 2007].

Msheireb Properties (2013) **Msheireb Downtown Doha** [Online], Available: http://www.msheireb.com/projects/msheirebdowntowndoha.aspx

Qatar Rail (2012) **Doha Metro** [Online], Available: http://www.qr.com.qa/English/Projects/Pages/Doha-Metro.aspx

TFL (2011) **DLR Station Data** [Online], Available: https://www.whatdotheyknow.com/request/107829/response/268523/attach/4/DLR%20Station%20Data.pdf

United Nations (2009) , **Urban and Rural Areas 2009** [Online], Available: http://www.un.org/en/development/desa/population/publications/pdf/urbanization/urbanization-wallchart2009.pdf