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Remodel, Recycle or Rebuild? - Addressing the Fire Safety Challenges of Repurposing Skyscrapers
改造、再利用还是重建？——研究摩天大楼再规划所产生的消防安全挑战

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Simon Lay是CTBUH 成员，同时也是英国特许消防工程师。在过去的20年，他领导和致力于大量的高层建筑消防策略设计，其中包括获得CTBUH高层建筑奖项的曼彻斯特毕森塔， 伦敦的碎片大厦和Strata 大厦，孟买的印度塔，迪拜的帆船酒店，以及其他全球众多的建筑项目。在不进行高层建筑设计的时候，Lay是一位山地自行车运动爱好者。

Abstract | 摘要

Some of our established world cities are already facing the challenge of older tall building stock that is no longer relevant to the most commercially attractive uses. One of the biggest challenges faced by any re-purposing of high-rise buildings is fire safety because there has, in the past, been a tendency to minimize fire safety costs by tailoring solutions as closely as possible to the building's perceived needs – but needs change. By reference to trends in tall building design and legacy building examples, the drivers for refurbishing and re-purposing tall buildings are explored along with the fire safety challenges that result. Solutions relating to existing building stock and planning for future reuse in new buildings are discussed.

Keywords: Architecture, Density, Fire Safety, Recycling, and Retrofit

我们在全球所建设起来的一些城市正在面临旧的高层建筑不再具有商业吸引力的挑战。高层建筑的任何方面的再利用所面临的最大的挑战是消防安全，因为过去曾倾向于通过缩减解决方案以尽可能的贴近建筑的感知需求从而将消防安全成本最小化， 但这需要改变。通过参考高层建筑设计趋势和遗留项目范例，高层建筑的改造者或是再利用者最终选择探讨消防安全挑战。有关现有建筑的留存和新建筑未来重复使用正在讨论之中。

关键词：建筑、密度、消防安全、循环利用、改造

The Case For Refurbishment & Re-Purposing

Countries are continually building more tall buildings. Data from the CTBUH Skyscraper Center[1] demonstrates that we are seeing more consistency in the build rate within well establish cities such as London, New York, and Chicago (Figure 1). When this information is coupled with census data[2] it can be seen that not only is the number of tall buildings going up, the rate of tall building development is outpacing even occupancy growth. This might

翻新与再规划案例研究

在世界各国，越来越多的高层建筑拔地而起。CTBUH摩天大楼中心1的数据表明，在一些业已发展良好的城市，如伦敦、纽约、芝加哥等，我们见证着其争先恐后发展趋势与速度城市（图1）。与人口调查数据相结合（例如：维基百科数据2）我们可以看出，不仅仅是数量，高层建筑还在增长速率方面令人惊叹，甚至超过了房屋居住率的增长。这一现象在新兴经济体，如中国和中东地区并不鲜见。但是，在有着悠久高层建筑历史的城市中同样的

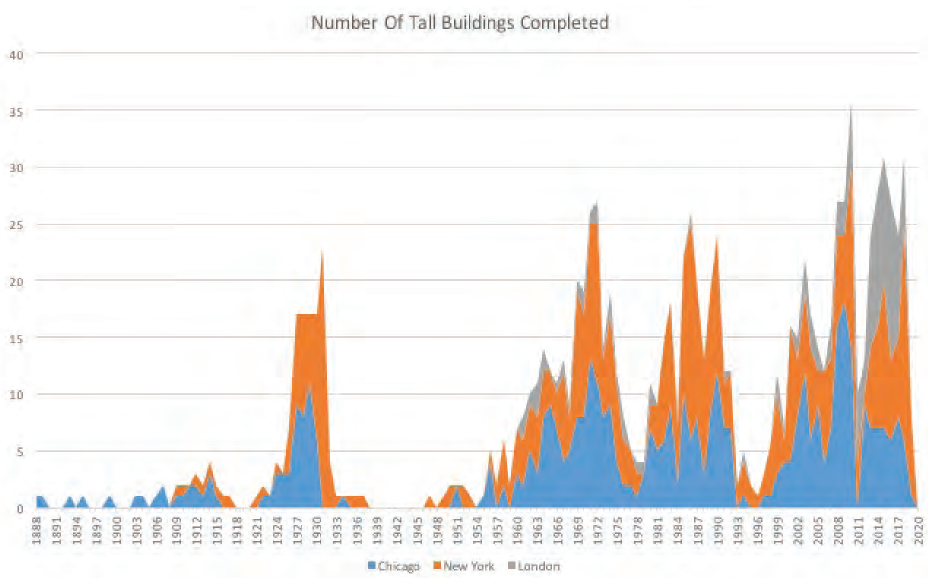

Figure 1. Rate of tall building completion per year (Source: Simon Lay)
图1. 每年建筑的完成数量（来源：Simon Lay）

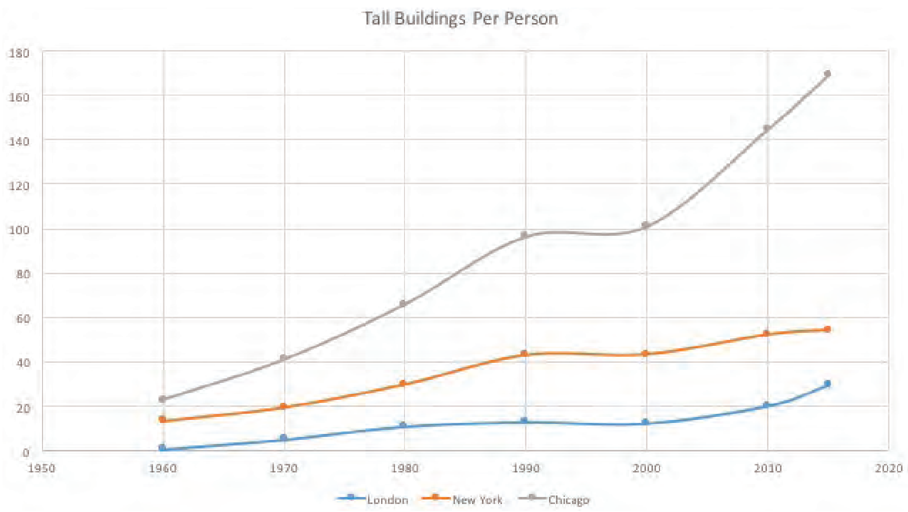

Figure 2. Ratio of tall buildings per person (Source: Simon Lay)
图2. 人均高层建筑面积（来源：Simon Lay）

be expected in emerging economies such as China and the Middle East region. However, the same is true, even in cities with a long established tall building heritage. The ratio of tall buildings per head of population has been steadily increasing and is now continuing to increase. In some cases, such as Chicago, the rate of recent increase in this ratio has been very significant, as shown in Figure 2.

However, we also know that the types of tall building are changing. In London for example, New London Architecture (NLA) identified that the current wave of tall buildings, taking us towards 2025, is expected to comprise of approximately 80% residential stock.

The urbanization of our cities is mainly attributed to new residential high-rise projects. In established cities like Chicago, populations in the inner city areas were declining, but are rising again as high-rise residential becomes the norm. We are building proportionally fewer high-rise commercial buildings, and yet the cities are growing.

There are several possible outcomes from this changing tall building demographic. Either the current stock of tall, non-residential buildings risk being converted to residential, or they will be retained and need to adapt to reflect a change in workplace patterns. All those people must be working somewhere, so if the population is going up but the rate of tall commercial buildings is not matching that rate, then the existing workplaces must undergo change.

In the UK we are seeing both of these changes occurring. In some instances, we are also seeing political changes that impact building use. A recent change in UK planning laws means that it is now considerably easier to convert a commercial building to residential use than it was previously.

The reuse of buildings might relate to either the refurbishment of buildings (where the occupancy type remains the same as before) or repurposing (where the occupancy type changes from one to another).

There has also been a trend within the existing high-rise residential stock whereby a long standing tradition of dramatic demolition scenes cheered on by jubilant former high-rise dwellers has been replaced in many instances with refurbishment of older social housing schemes into accommodations more suited to the current private renting sector.

There are good economic drivers for refurbishing and remodeling existing buildings. Based on recent tall building cost models by Alinea,[3] approximately 40% of the building value is tied up in the basic shell and structure, with roughly half of that committed to the building façade. There are cost challenges associated with refurbishing buildings (it is more costly to fit things internally to a building after completion than during construction), but the underlying value of the shell of a tall building is a compelling case for reuse on its own.

Alongside cost, there is a parallel sustainability driver for reusing the building shell. As Oldfield noted in his CTBUH paper (Shanghai 2012),[4] the embedded carbon from the initial construction of a tall building is roughly 20–40% of the total lifetime carbon. In the case of 30 St Mary Axe (Figure 3), a detailed review showed that a modern, low-carbon building like this still has 33% of the total lifetime carbon embedded in the original construction.

There are therefore compelling arguments for reusing buildings rather than demolishing and rebuilding. But there are also significant obstacles to achieving the desired efficiencies in the refurbishment or repurposing

事情也正在不同寻常地发生。在图2所显示的案例中（如芝加哥，近期增速尤为显著），高层建筑人均比例一直在稳步上升，并且这一趋势还将继续保持。

不过，与此同时高层建筑的类型也在发生变化。比如在伦敦，NLA表示，当前兴起的高层建筑浪潮预期将持续至2025年，并产生城市80%的住宅存量。

发生在我们周围的城市化进程，主要归功于新的高层住宅项目。像芝加哥这样的著名城市，市区内人口数量曾一度处于下降趋势，但随着高层住宅建设的不断发展，城市人口数量再次增长。我们正在做的是按比例增加少数商用高层建筑，城市也由此得以发展。

从人口学角度来说，高层建筑的增加将产生一系列可能性。当前高层建筑存量与非住宅建筑所存在的风险可能会转嫁给住宅建筑，或者根据市场环境的变化采用新的运作模式。在人口增加的前提下，如果商用建筑建设的速度滞后于需求，那么新增工作岗位上的这些人就必须找到工作场所，现有的工作环境就会发生改变。

在英国，上述两种结果都已发生。一些案例中，我们还能够看到政治变化对建筑使用的影响。最近，英国规划法进行了修改，这意味着将商用建筑改变为住宅用途简单了很多。

建筑物重新规划用途，可能意味着翻修（住户类型保持原样）或者再规划（住户类型发生改变）。

并且，我们已经认识到老式高层住宅领域存在的一种趋势，在很多案例中受到前任

Figure 3. 30 St Mary Axe, London (Source: Aurelien Guichard)
图3. 伦敦圣玛丽斧街30号（来源：Aurelien Guichard）

process, which are necessary if the cost and sustainability goals are going to be met. Because fire safety is regulated, the challenges associated with it represent significant risks to unlocking the reuse process.

Key Fire Safety Challenges

There are two primary mechanisms for how refurbishments can result in fire safety challenges:

- Occupancy based code parameters.
- Changes in building codes with time.

Occupancy based code parameters

The mechanisms relating to occupancy based code parameters tend to have an impact on the reuse of buildings, while historic changes in building codes tends to impact both refurbishment and reuse.

Prescriptive building codes such as NFPA 101,[5] the IBC,[6] or the UK Approved Document B[7] rely on occupancy type as the fundamental basis for determining fire safety risk. In particular, code requirements relating to means of egress are heavily dependent on occupancy type. Sometimes the reasons for using occupancy type as a means of determining fire safety requirements are readily justified. For example, office buildings have a higher density of people than residential apartments do.

In other instances, the code basis for changing guidance based on occupancy type may be less clear. For example, the reasoning behind longer travel distances being considered the acceptable norm in offices compared to the shorter distances expected in apartments is not immediately obvious. The reasoning behind such rules relate to differences such as fire risks and whether occupants might be awake or asleep. The basis of such recommendations is often historical data, whereby the prescribed rules have led to stable fire casualty rates.

However, with tall buildings, some code requirements may be or at least appear to be relatively static across numerous occupancy types. For example, most tall buildings code requirements dictate the same structural fire resistance irrespective of occupancy type. Most tall building codes also insist on sprinklers in all tall buildings and charged stand-pipes for fire fighting. Although in the case of sprinklers, this does not necessarily lead to solutions that are insensitive to building reuse. Sprinkler designs change with occupancy type, and while items such as range piping are likely to be changed as a result of the reuse process anyway, main feeder risers, tanks, and pumps can all be

	Original Use 原用途		New Use 新用途	Negative Implications On Design 对设计的负面影响		
				Low 低	Medium 中	High 高
Egress Capacity 出口容量	Office | 办公	»	Office | 办公	X		
	Residental 居住	»	Residental 居住			X
Travel Distance 疏散距离	Office | 办公	»	Office | 办公			X
	Residental 居住	»	Residental 居住	X		
Structural Fire Resistance 结构性防火性能	Office | 办公	»	Office | 办公	X		
	Residental 居住	»	Residental 居住	X		
Sprinklers 喷头	Office | 办公	»	Office | 办公		X	
	Residental 居住	»	Residental 居住			X
Fire Fighting Standpipes 消防竖管	Office | 办公	»	Office | 办公		X	
	Residental 居住	»	Residental 居住		X	
Pressurisation 增压	Office | 办公	»	Office | 办公		X	
	Residental 居住	»	Residental 居住			X

Figure 4. Negative implications on design arising from a change of high-rise building use (Source: Simon Lay)
图4. 改变高层建筑用途对高层建筑设计的负面影响（来源：Simon Lay）

tuned to original building occupancy type and require extensive replacement if the occupancy type changes.

Items like standpipes or hosereels might well be required across all occupancy types and hence might be thought of as being relatively unaffected by reuse. However, the location of fire fighting water supplies can be heavily impacted by a change of fit-out, as areas previously accessible become cut off from the fire fighting route.

There are other fire systems required across different occupancy types in tall buildings that may appear to be insensitive to change of use, but which can be impacted. For example, pressurization systems may rely on building leakage data, which can be impacted significantly by the different levels of subdivision typical to different occupancy types.

The table below (Figure 4) shows some of the common core fire safety requirements, which prescriptive codes vary with occupancy, and how the repurposing of a building between office and residential might typically be impacted.

The implications on design arising from change of use and repurposing are different depending on which way the change is enacted. For example, as offices are designed for a higher occupancy capacity, then there would be residual egress capacity if changing from office to residential, but conversely potential egress challenges if changing in the other direction.

As travel distances in residential buildings are typically much shorter than allowed for in offices, the distribution of cores in residential buildings will typically readily accommodate

住户欢迎的爆破拆除方案已被翻新计划所取代，以适应当前私有租赁行业的需求。

现有建筑的翻新与改造背后由高回报的经济利益所驱动。根据最新的Alinea3高层建筑费用模型，建筑物总造价的40%直接用于基础外壳与结构，其中大概一半成本用于建筑外立面（竣工后改变建筑内部所花费成本远大于在建之时），因此对于用途再规划的高层建筑，改变自身外立面设计是一种拥有潜在价值的方案。

除了成本因素之外，重新设计建筑外墙的另一原因是建筑的可持续发展性。如Oldfield4在他的CTBUH文章（上海2012）中所提到的，高层建筑初始施工中所形成的植入碳排放，占整体生命周期碳排放总量的20%至40%。St Mary Axe30号的案例中（图3），某详细评估指出，尽管现代低碳环保技术在建筑项目中得以应用，但仍有33%的建筑生命周期总碳排放量于原始施工阶段被植入。

因此，上述原因成为建筑用途再规划优于建筑拆除与重建的有力论据。但翻修与再规划的理想目标效益，以及建筑成本与可持续发展目标的实现，仍存在重要的问题亟待解决。例如：问题可能来自消防安全法规的制约，这些法规代表着建筑用途再规划过程中潜在的重大火灾隐患和由此产生的消防安全难题。

重点消防安全难题

有两种原因导致建筑物翻新工程种产生消防安全问题：

- 建筑使用率参数的规定
- 建筑法规的时代变迁

offices where the maximum travel distances are much greater. However, there can also be a significant issue in some jurisdictions where the number of cores required can be lower for a residential design compared to an office level of occupation. For example, in the UK high-rise residential schemes are allowed to have a single stair while offices are expected to have multiple cores.

Residential sprinkler systems are often combined with potable water supplies and designed for a small number of heads operating, while office systems require larger tanks, pumps, and risers as they must address a longer period of operation with more heads activating.

Changes in building codes with time

Building codes tend to move at a relatively glacial pace and arguably the rate of change for well established codes is slower now than it was previously. This would make sense as codes are supposed to change to improve safety and if you achieve that aim, then there is less scope to make other changes to further improve safety.

However, in some cases building codes change to reflect technological advances. A good example of this is the emergence of codes that outlaw combustible insulation in façade systems on high-rise buildings.

Changes of this type can introduce a tension in the design and approval process. Many building codes (or the regulatory process within which they operate) include a principle that maintaining the same standard of safety or betterment is considered acceptable during refurbishment projects. As a result of this principle, conditions which might be known to be dangerous may be allowed to persist.

There may be a catch-all in some building codes that requires designers to ensure that there is an overriding obligation to ensure safety, whether something is restricted or permitted by code or not. For example, UK legislation includes such a provision. However, the mechanisms by which such legislation might be applied can be complex as it may be considered prohibitively costly to make major changes to an existing building façade, and the same legislation may well include restrictions which ensure that only practical measures need to be made. Prohibitive expense can be a legitimate reason to consider a change impractical.

Where a change of use takes place during a repurposing process, then this can often trigger the application of current standards rather than

建筑使用率参数的规定

基于规定参数的建筑使用率所导致的安全问题，其形成机理通常在建筑物用途再规划工程中产生影响，同时，建筑法规的历史改变所造成的影响，可能在建筑物翻新与再规划两类工程中产生安全问题。

规范性建筑法规，如，NFPA 1015，IBC6或者英国政府批准文件UK　B7都将建筑使用类型作为判断消防安全风险的依据。特别是法规中对于出口设施的要求细则，非常倚重于建筑的使用类型。通常根据建筑使用类型决定消防安全要求，原因是而易见的。比如，办公楼内的人员密度要大于住宅公寓，因而相应安全规范也就不同。

其它一些案例中，指导建筑改变使用类型的法规内容可能没有那么明晰。例如，办公楼中规定的步行距离较长，其制定原因容易被理解与接受，而相对的公寓住宅中规定步行距离较短的原因就没那么显而易见。这些法规成因存在诸多差异，比如，火灾风险与住户清醒与睡眠状态的关系，建议应依据常规性历史数据来制定法规，可以避免出现严重的火灾事故。

但是在高层建筑里，住户使用类型较多，一些法规要求多多少少有些固化。例如，大多数高层建筑条例强制规定了相同的消防结构而没有考虑不同的用户类型。许多高层建筑法规坚持在所有高层建筑中安装喷洒灭火装置并利用储水管进行消防灭火工作。尽管建筑物用途再规划工程对于喷洒灭火装置并不产生实质性影响，因而不必为此设计解决方案。但如果根据使用类型的改变而变动喷洒消防设计，再规划项目过程中管道铺设也必须随之改变，包括主要竖管，水箱、泵等所有针对原有使用类型的设备都需要大规模更换。

由于储水管与消防软管盘等设备在任何住户类型条件下都非常必要，因此可以认为建筑物再规划对此类设备没有太大影响。不过消防供水位置可能受到严重影响，所在区域由于安装设备的改变也不再与消防通道保持畅通连接。

一些不同用户类型的高层建筑通用消防系统，其功能对于建筑用途改变并不敏感，但仍会受到影响。例如，密封系统的性能表现依赖建筑渗漏参数，不同使用类型的不同楼层区域子系统划分对其性能表现造成的的冲击尤为明显。

上表（图4）列出了一些普遍性的核心消防安全规定，法规依据建筑的不同用途，对办公与住宅建筑再规划项目进行规范。

改变建筑用途或者说再规划的设计内容取决于项目的实施方式。例如，使用密度高的办公楼在改变为住宅用途时，过多的出口通道会导致冗余，但相反的，如果是其它方向的功能改变则可能产生潜在的疏散能力不足的安全性问题。

住宅建筑中的步行距离明显短于办公楼所允许的最小距离值，住宅建筑的核心区域最大行程距离空间通常较为充裕，较容易进行办公用途改造。但是，即便如此在一些司法辖区的规定中存在的一个明显的问题：相对于办公楼使用等级而言，住宅楼所要求的核心区域数量远远少于办公建筑。比如，在英国住宅项目设计只允许存在一个楼梯系统，但同时办公建筑却需要多个核心区域（拥有多个楼梯系统）。

住宅建筑喷洒灭火系统通常与饮用水源共用，并且灭火喷洒器设计数量较少，同时，办公系统需要较大的水箱、泵与竖管系统，同时必须要对更多灭火终端长期工作的问题加以研究。

建筑法规的时代变迁

建筑法规的变革相对来说步调缓慢，并且公认完善的法规，其更新速率更慢于以往。道理在于法规设定用来改善安全环境，如果安全目标已达成，那么未来为进一步改善安全而修改法规的程度必然小于前期。

有时科技进步也会导致建筑法规的改变。其中较典型的一个案例，是关于高层建筑外墙系统违法易燃保温材料法规的制定。

此类改变给设计工作与验证过程带来新的压力。许多法规（或者法规落实的管理过程）包含的一个原则是在建筑翻新项目中维护以往的安全标准或者考虑可以接受的安全改进措施。但这一原则将导致一些已知的危险环境因素得以继续存在。

在一些建筑法规中可能存在笼统性的条款，要求设计者确保按照法规允许与禁止的规范行事，而其中最重要的准则是安全保证。例如，英国法律中就包含这样的条款。但是在法律实践工作中所面临的情况可能会非常复杂，例如，在现有建筑外墙上做重大改变的成本可能会非常昂贵，但恰好同一法规包括的限制性条款规定，这是唯一可采用的实际措施，因此项目改造就会因为昂贵的成本而无法进行下去。

建筑物用途再规划过程中，发生的用途改变通常引起当前标准制定而非保持原始建造时的标准。因此，如果要避免重覆建筑外层的昂贵成本，有必要通过其它手段、途径建立更高的消防安全等级。

在许多案例中，法律的改变能够实际上减少应用于建筑的消防安全规定。举例来说，历史较长的办公建筑中，上述情形可能发生。随着时代变迁，建筑应用的安全条款可能累积的非常繁杂，超出了维护安全性所需要的程度。有关案例可参考英国国家标准BS 99998　，标准在2008年引

Figure 5. Lakanal House fire (2009) (Source: Independent)
图5. Lakanal House大火（2009）（来源：Independent）

Figure 6. Royal Mail House, Leeds (1975) (Source: Yorkshire Post Newspapers)
图6. 1975年的利兹英国皇家邮政局（来源：Yorkshire Post Newspapers）

Figure 7. West Point (2005) – reuse of Royal Mail House, Leeds (Source: Rightmove)
图7. 2005年的西点军校——利兹英国皇家邮政局的再利用（来源：Rightmove）

maintaining the standard at the time of original construction. It may therefore be necessary to find ways of achieving a higher standard level of fire safety through other measures if a full re-cladding of the building is to be avoided.

In many cases, changes in legislation can actually reduce the fire safety provisions expected in a building. This may be true for example in office buildings where the historical pattern of fire safety has, over time, suggested that fire safety provisions may be more onerous than is required to maintain adequate safety. An example of this could be considered the British Standard BS 9999[8] which has since 2008 introduced an element of risk assessment within the determination of egress requirements such that a building assessed using this code can have a higher occupant capacity than one which was design using other prior standards. This kind of variation can be useful in refurbishment as it may, for example, allow a greater occupancy to be accommodated in an office building that can therefore better respond to changes in working patterns.

There are also cases where changes in non-fire legislation can result in unintended consequences during refurbishment. The Lakanal House fire in 2009 (Figure 5) highlights the dangers that could occur when inappropriate insulation products are introduced in an effort to bring existing high-rise housing stock up to current thermal and damp resistant standards. The fire led to the death of six people and 20 serious casualties.

Another element of code changes with time which should be noted is the general aggregation of codes and the reduction in location or owner specific codes. In some jurisdictions, government agencies may have their own separate building codes which vary from those used in non-governmental buildings. Variations seen in building codes within different states in the US have, for example, reduced over time with the wider introduction of Uniform Building Codes and the NFPA standards.

Government building specific codes might not always introduce a higher standard of fire safety (although this is normally the case). On a project in Leeds in the UK, a former post office building was converted to residential use in the West Point project. The 17-story scheme was originally constructed in 1975. During the repurposing studies, it was determined that the building structure only achieved a fire rating of approximately 90 minutes, something that arose from the government requirements at the time of original construction (Figure 6). As a repurposed scheme, current building codes were applied and a 120 minute standard of fire resistance was expected (Figure 7). The resolution of this challenge is described in the following section.

Solutions to Fire Safety Challenges Of Reuse

Finding solutions that can overcome the fire safety challenges in reused buildings should be considered for both the existing stock of buildings and for future buildings that can be made more resilient to reuse.

Existing Building Stock Solutions

Considering the West Point example in Leeds, the differences between Figures 3 and 4 show how some of the challenges were

入建筑出口需求风险评估，使用这一标准将使建筑物的使用率提高。此类变化，从各方面意义而言，对于建筑翻新项目都非常有用，例如允许办公建筑容纳更多使用人数可使建筑项目更好的应对工作模式的变化。

其它一些翻新项目案例中，非消防安全法规导致了意想不到的结果。当不合理的绝缘材料应用于高层住宅隔热与抗潮湿标准时，就会产生十分危险的结果，例如2009年拉卡纳尔大厦火灾（图5），大火导致6人死亡，20人严重受伤。

随时代变迁的法规中，另一需要引起注意的因素是一般法规集合与地方法规以及所有者特别规定之间的差异。在一些司法辖区，政府机构可以有自己独立的建筑规范，并且与那些应用于非政府建筑中的法规不尽相同。这些差别可以见诸于美国各州的建筑法规，例如，统一建筑法规（Uniform Building Codes）与NFPA标准中被广泛引用的减少超时工作的规定。

政府建筑特别规定并不总是引入更高的消防安全标准（虽然，通常是这样的）。在英国利兹的West Point项目中，一座前邮政大楼被转化为住宅用途。17层建筑项目的原始蓝图设计于1975年。再规划研究中发现，源于建筑最初建设时的政府要求，原始建筑防火等级大约只有90分钟耐火度（图6）。作为再规划项目（图7），当前建筑标准要求建筑抗火等级达到120分钟。这些问题的解决方案在下文中加以介绍。

建筑再利用中消防难题的解决方案

建筑再利用过程中消防安全难题的解决方案研究，不仅关系到现有建筑，而且也是

overcome. The upper floors of the building had previously been an office typology, and this permitted longer egress distances than would be appropriate for the residential use, which was applied in the repurposing. To overcome the egress challenge and achieve appropriate apartment layouts, there was little option but to add additional stair cores which can be seen projecting from the building in Figure 4.

However, an architectural solution to the inadequate fire resistance to the building structure was not possible. Overcladding the existing concrete frame could have been considered, but this would have been prohibitively expensive and would have created approval challenges as it would have relied on a mixing of different fire protection methods that are not simply additive in nature. You cannot assume that placing 30 minutes worth of plasterboard fire protection on the outside of a 90 minute column will deliver 120 minutes of fire resistance because you may create unanticipated consequences such as changes in the spalling nature of concrete.

Instead, the approach taken was to look at the types of fires which might be present and evaluate the fire severity that the building frame would be exposed to in the refurbished condition. This approach has been subsequently used on other projects.

Fire severity can be thought of as a function of the temperature of exposure and the duration over which exposure takes place. These factors are functions of the available fire load and ventilation. Increasing fire load will increase peak temperatures and fire duration. Increasing ventilation will increase peak temperatures but reduce fire duration and conversely reducing ventilation will reduce peak temperatures but may lead to much longer duration fires.
By considering the smaller fire compartment sizes resulting from a residential fit-out and the reduced fire load density in residential compared to office type occupancies, it was possible to show that the load on the structure induced by a fire would be less for the residential case and consequently show that the existing 90 minute fire resistance was more than adequate to maintain stability in a fire condition. This solution unlocked the reuse of the structural frame and reduced the carbon contribution of the scheme by approximately 20%.

Often the solution to reuse is the application of alternative solutions in a performance based approach. Evaluating how the building risks have changed from an original design to the condition in the reuse scheme can unlock solutions. This approach can be especially useful when new buildings introduce better fire safety systems.

For example, traditional fire alarm systems in an existing office building might be replaced during refurbishment with voice alarm systems or a system which permits phased evacuation when only simultaneous evacuation was possible previously. This approach can allow a significant increase in occupancy capacity.

Many older high-rise buildings do not have sprinkler systems installed. This may be particularly true of residential schemes. The application of a performance based approach to develop alternative solutions with the introduction of sprinklers can allow significant improvement to be demonstrated, enabling fire safety challenges to be overcome. This approach may be particularly relevant when considering how challenges like existing cladding systems may be overcome.

Future solutions – planning for reuse
If we can plan buildings so that they are more readily repurposed or refurbished, then, by saving up to 40% of the building's lifetime carbon (by removing the need for the building to be demolished and rebuilt), we are in position to make greater sustainability advances than almost any other design change.

The challenge of course is that traditional approaches to designing for maximum flexibility can be expensive. It is not economically viable to add extra or wider stairs to a tall building on the off-chance that it may be reused later in a manner which will make use of those stairs. Making a less efficient building in the first place, in the hope that overall it will turn out more efficient, requires extraordinary commitment and progressive thinking which goes well beyond the financial cycles of all but the most forward thinking of clients or developers.

There is however a reasonable balance that can be achieved. Too many approval regimes focus on signing off the building in its first incarnation. "Day one" approvals for schemes, which do not consider the potential legacy of the building, are something of a tick-box exercise in meeting code but not the needs of the building and society at large.

Designers, clients and approvers all have a role to play in moving the agenda forward. Approvers need to ask clients and designers to consider the legacy situation. Clients need to ask designers to include legacy options in their appraisals, and designers need to step up and lead the technical approach to planning for reuse.

未来建筑再利用弹性设计中需要仔细考察的问题。

现有建筑解决方案
考察利兹的West Point项目案例，图3与图4的差别表明了这个难题如何被克服。前期作为办公用途的顶部楼层拥有长距离的出口通道，适合在用途再规划改造中作为居住性使用。为了克服出口难题并建立合适的公寓布局，除了增加额外的楼梯间外或许别无他法，相关工程见图4建筑。

但是，建筑结构解决方案中如果存在耐火性不足的问题，那么方案就不具备可行性。虽然在此情况下可以考虑混凝土结构添加外保护层方案，但这一方案非常昂贵，而且会在审批上遇到困难，因为采用混合防火模式并不等同于简单的相加。不要妄想将30分钟耐火度的石膏板添加到90分钟耐火度的立柱上会产生120分钟耐火度，因为混凝土开裂的自然属性会使结构产生不可预测的结果。

替代性的方法基于审查翻新环境中结构可能面对的火灾类型以及烈度。这些方法已经在随后的其它工程上得以应用。

火灾烈度通过灾害发生时暴露结构的温度与过火时间参数来衡量。涉及因素包括有效火灾负载与通风系数。增加火灾负载可增大温度峰值与燃烧时间。增加通风系数会增加温度峰值但降低燃烧时间，相反，削弱通风功能会降低温度峰值但大大延长燃烧持续时间。

考虑到住宅设施较小的防火间尺寸和相对办公建筑较低的火灾负载密度，这可能表示住宅案例中火灾引起的结构负荷较小，因而当前90分钟的耐火度足以使结构在火灾条件下维持稳定。这一解决方案不仅实现了再利用项目结构框架的可行性并且减少了设计中20%的碳排放量。

经常性的，再利用项目解决方案是替代解决方案基于方法绩效的应用。再利用规划设计条件下，对改变原有设计的的建筑进行风险评估，可产生解决方案。当新规划的建筑需要引入更好的新一代消防安全系统时，此方法非常有效。

例如，传统办公建筑中存在的火灾警报系统可在翻新工程中被声音警报系统取代，或者可以使用一个允许分段撤离的系统改变以前只能同步撤离的情况。这些方法的应用可显著增加建筑的使用能力。

一些老式高层建筑没有安装喷洒灭火系统，在住宅型设计中此类问题尤为突出。实践证明，通过应用绩效评估方法开发的喷洒消防设备替代解决方案，能够显著改善建筑物消防条件，从而解决一系列的消防安全难题。考虑到工程所面临的一些难题，如覆层系统，对上述方法应用的相关性应给予特别重视。

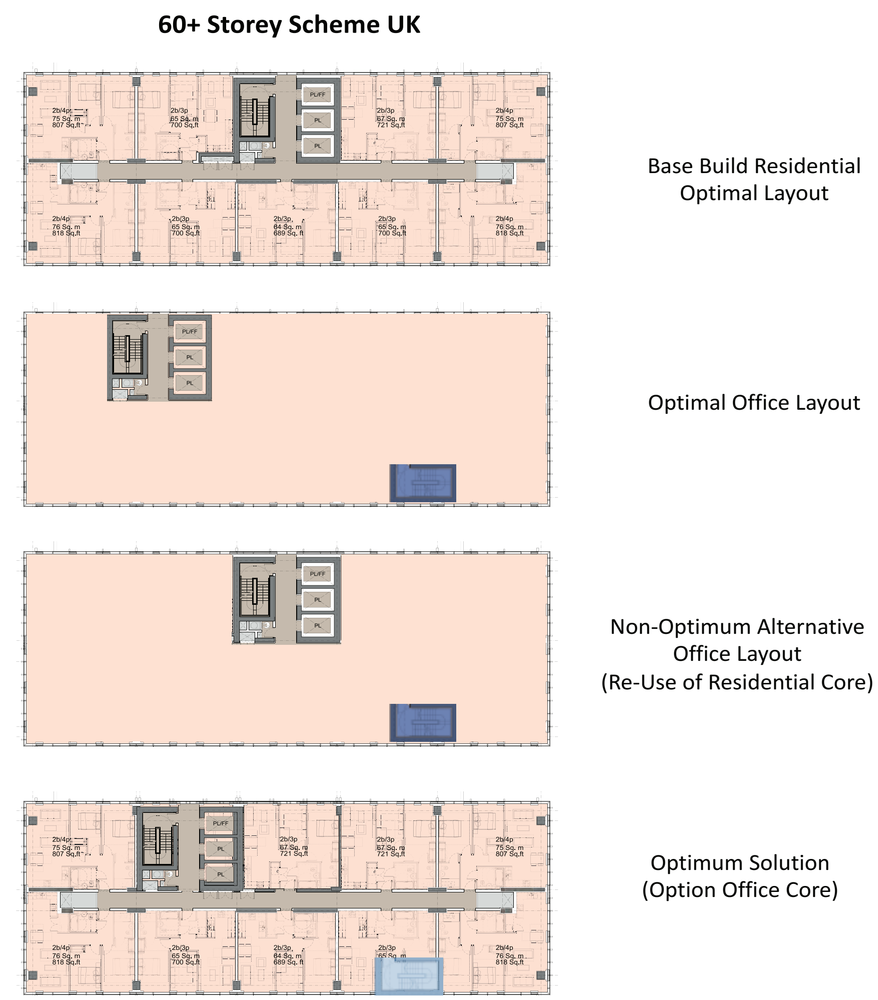

Figure 8. Pre-approval of reuse options an a 60-plus-story scheme (Source: Simon Lay)
图8. 增加60层的再利用预审方案（来源：Simon Lay）

Often, unlocking reuse potential in a new scheme does not cost more, nor does it radically change the design. From a fire safety design perspective, it may simply be a matter of applying better analysis techniques to understand how the building might respond to different uses or layouts. It may also require the application of more complex, performance based design solutions rather than following a code approach which immediately tries to define the building as a specific occupancy type from the outset.

By taking due regard for legacy conditions, the fire engineer for tall buildings should develop not a "fire strategy," but a "fire code" for each building. The fire code approach means pre-approving an operational envelope within which the building can change and function over time. This approach has been considered for a 60-plus-story scheme in the UK (Figure 8).

The scheme in figure 8 was designed in its first incarnation as a residential development. However, there was a recognition that some lower floors might convert to office in due course and it was necessary to seek an efficient compromise solution to make this viable.

In the UK, single stair high-rise residential buildings are permitted and have been demonstrated to offer acceptable standards of safety. Single stair office schemes are not the norm, but based on statistical data relating to fire safety, there is little reason to suggest that such single stair office schemes could not safety be developed. However, standard code recommendations would lead to two stair designs for offices.

So, as shown in figure 8, to change from residential to office would typically require an extra core to be inserted. This would produce an unattractive office configuration due to the narrow gap between the cores.

If the base-build residential core is moved across, then the extra office core can be added later with sufficient distance between the two cores to make it a viable option. The office core can be added only when needed by allowing for a "soft spot" in the floor plates. However, moving the original residential core to one side could be problematic as it creates a long travel distance from the furthest apartment in the residential base-build configuration.

未来解决方案——再利用规划

如果我们能够改进建筑设计，使它们更易于再规划用途和翻新，就会节约40%的建筑生命周期碳排放总量（通过省略建筑拆除与重建的必要性），因此此方法推动在环境可持续发展与进步方面优于其它任何设计改变。

采用传统构建方法，最大化建筑项目的再利用可塑性，其困难之处在于昂贵的成本。建造额外或者拓宽的楼梯间以备将来建筑物再规划使用的模式，从经济效益来说几乎不具备可行性。首先建设低效率建筑以期未来项目整体效益的提升，需要非凡的承诺与先进的思想，需要客户与开发商拥有超越财务周期局限的最大前瞻性思考。

然而，要达到合理的平衡性也不是不可能。太多的审批制度集中于建筑初始形态的竣工阶段。项目规划的 “首日”审批制度并没有对建筑的潜在存续价值进行仔细的考虑，它就像一张勾选题试卷，迎合评判规则但不满足建筑利用与社区利益的最大化要求。

在此类项目议程中，设计者、客户与审批单位都需要扮演推动者的角色。审批单位需要询问客户与设计者建筑存续价值的情况。客户需要向设计者询问存续价值评估中的可选项目而设计者肩负着采用技术手段规划建筑未来再利用的任务。

通常，解锁新方案中潜在的再利用功能不会显著提高造价成本，或者不会从根本上改动计划。从消防安全设计的角度，解决之道可能只是一个使用更好的分析技术进而理解建筑如何响应不同使用及环境布局的问题，或者还需要更加复杂的、基于性能设计的解决方案，而不是仅仅依照法规手段，其局限性在于尝试在初始阶段就将建筑定义为某一特定使用类型，不利于建筑再规划的实现。

通过恰当考虑存续条件，高层建筑的消防工程师应当开发“消防法规”而非“消防策略”。消防安全法规手段意味着对经历岁月后的建筑改造与功能实现的一揽子行动方案进行预先验证。英国一项60层大楼项目计划已经在考虑应用这一方法（图8）。

图8中，建筑规划设计的最初阶段是住宅项目。有观点认为较低楼层可通过适当的方法转换成办公建筑，因而需要寻求一个高效的兼容方案使其可行。

在英国，单一楼梯间的高层住宅建筑已获得允许，并通过验证能够提供可接受的消防安全标准。但是单一楼梯间写字楼设计有些不同寻常，而且消防安全数据分析，也无法为这样的办公楼楼梯间设计的安全性提供合理依据。不过可以通过标准法规

Fortunately, members of the Olsson Fire & Risk team have developed many residential projects with extended travel distances within the common areas. These include the CTBUH 2007 Best Tall Building Worldwide award winner – the Beetham Tower, Manchester (Figure 9).

The use of performance based design approaches to create solutions or reveal the flexibility already within established design solutions can provide a powerful means of unlocking tall building designs for future reuse. This kind of approach avoids the mistake of standard codes which lock a building design to a specific configuration and use, restricting the future re-imagination of existing buildings.

建议的办公楼双楼梯间设计来解决这一问题。

所以如图8所示，建筑用途从住宅向办公转变通常需要增加核心结构。这将导致建筑核心之间狭窄的空间，从而产生不太招人喜欢的办公环境布局。

如果移动基础建筑的住宅核心结构，其后增加的办公建筑核心可在核心之间保持充足的距离，以此使整体设计具备可行性。通过在楼层板上设置“软点”（ soft spot），办公建筑结构核心可以在需要的时候被添加。但是移动原始住宅核心到另一端可能会产生困难，因为要从住宅型建筑布局中最远端的公寓开始建立一条长距离的行进空间。

幸运的是，奥尔森消防与风险控制团队（the Olsson Fire & Risk team）已经在很多住宅项目中利用公共空间创造了扩展行进空间。其中包括获得CTBUH 2007“最佳建筑奖”的项目（图9）。

使用基于性能的设计方法制定解决方案或者发掘既有解决方案中的设计弹性，在高层建筑设计中为开发未来再利用功能提供有力的工具。此类方法避免了标准法规中所产生的错误，这些法规用特定布局与用途锁定了建筑设计，限制了现有建筑的未来再规划能力。

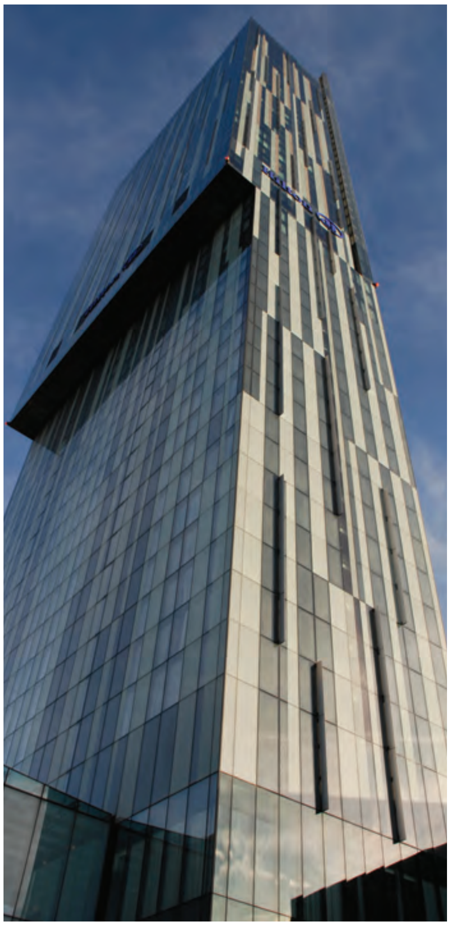

Figure 9. Beetham Tower, Manchester, which has extended travel solutions (Source: Paul Hermans)
图9. 曼彻斯特毕森塔，已经向旅游方案扩展（来源：Paul Hermans）

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