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Unpacking Composite Construction: Global Trends

开箱复合结构：全球趋势

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Terri Meyer Boake is a Full Professor at the School of Architecture at the University of Waterloo in Canada. She has been teaching since 1986. She is the author of the "CISC Guide for Specifying Architecturally Exposed Structural Steel" (2011). She has recently published three comprehensive books on steel in architecture for Birkhäuser: "Understanding Steel Design: An Architectural Design Manual" (2012), "Diagrid Structures: Systems, Connections, Details" (2014), and "Architecturally Exposed Structural Steel: Specifications, Connections, Details" (2015). She is on the CTBUH Height Committee and is a member of the CTBUH Skyscraper Center Editorial Board.

博格・美亚・泰瑞女士是加拿大滑铁卢大学建筑学院的终身教授。从1986年执教至今。她是2011年出版的《复杂指令集计算机入门之暴露式钢结构建筑说明》一书的作者。她近期出版了三本和建筑钢结构相关的综合性书籍。分别是2012年出版的《建筑设计手册——钢结构设计解读》、2014年《网格结构——体系、连接及细部》和2015年出版的《暴露式钢结构建筑——规范、连接、细部》。她是高层建筑与都市人居学会成员，同时还是摩天大楼中心（CTBUH）编辑委员会成员。

CTBUH Research Project
CTBUH研究项目
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Abstract | 摘要

There has been a marked shift away from the use of steel as the primary structural system that had long been the Western standard for skyscrapers, towards a preference for reinforced concrete that is being quickly caught by the use of "composite structures." A study was undertaken to discover the more particular nature of composite construction beyond its general definition in The Skyscraper Center database in order to provide a finer-grained appreciation of construction practices that could assist designers and researchers in understanding the nature of these applications and the global impact of the same. This paper describes findings regarding the detailed nature of the evolution of composite construction types as are used in buildings 150m or taller. The research looks at the global distribution of the five identified primary composite types: concrete core with steel framing; concrete filled steel tubes; concrete encased steel; reinforced concrete columns; and precast concrete columns.

Keywords: Composite Construction, Concrete Encased Steel, Concrete Filled Steel Tubes, Global Trends, Steel Framing

长期以来，西方摩天大楼以使用钢材料作为主要结构体系，而现在随着复合结构的使用，更偏向于钢筋混凝土的应用，这个转变显而易见。本文研究目的旨在探索复合结构除摩天大楼中心数据库给出的广义定义之外，其更加特殊的本质。为帮助设计者和研究者解读这些应用的本质及它们在全球所产生的影响，提供更加精细的建筑实践分析。这篇文章描述了150米或更高建筑中，复合结构类型演变的细节及本质。本文重点研究已经确定的五种主要复合结构类型：钢结构框架–混凝土核心筒，钢管混凝土、钢骨混凝土、钢筋混凝土框架柱以及预制混凝土柱。

关键词：复合结构、混凝土包钢结构、钢管混凝土结构、全球趋势、钢结构

Introduction

The construction of tall buildings has had a marked shift away from a North American dominance that has lasted from the first steel skyscrapers in New York and Chicago in the early 1900s until the emergence of a new globalized field that is seeing a clear ascendancy in China and the Middle East in terms of quantity and height.

This research study is about the invention that has occurred in structural design to support the desire to build taller, and more specifically to the growing shift towards the use of composite construction and away from more traditional all-steel buildings (Figure 1).

According to CTBUH "a composite tall building utilizes a combination of both steel and concrete acting compositely in the main structural elements, thus including a steel building with a concrete core." The term composite was initially established through the work of Lawrence G. Griffis, P.E. through his 1994 T.R. Higgins Lecture titled "Composite Frame Construction" (Modern Steel Construction. October 1994. p. 36–47).

引言

从20世纪早期，芝加哥和纽约两地建造第一座钢结构摩天大楼以来，北美一直在高层建筑结构方面占主导地位，直到新的全球化领域的出现，高层建筑结构发生了显著变化，而中国和中东地区在这一领域，在数量和高度方面正呈现出明显优势。

复合型结构建筑日益增多，传统全钢结构建筑逐渐脱离视野，为了匹配建造更高更独特建筑的雄心，结构设计方面有了创新，这篇文章旨在研究结构设计上产生的创新（图1）。

根据世界高层建筑与都市人居学会称："一座复合型高楼利用钢材和混凝土结合，将其结合的产物作为其主要结构元件。因此，复合型高楼是带有混凝土核心筒的钢结构建筑。""复合材料"这一专业名词是Lawrence G. Griffis以"复合框架结构"为题在西奥多希金斯讲座中（现代钢筋结构，1994年10月，36–47页）中首次提出的。

在当时，Griffis的主要研究领域包括CFT系统、RC/SRC系统和RC/SRC墙壁系统。有趣的是，Griffis在1994年之前发表

Figure 1. The Poly Diamond Lantern Tower is diagrid structure in Beijing, China. It uses a concrete filled steel tube frame which is a type that is particular to Asia. (Source: Terri Meyer Boake)
图1. 坐落于中国北京的保利“钻石灯笼”塔楼，是一座钢管混凝土框架结构建筑物，它所使用的钢管混凝土框架类型是亚洲特有的。（来源：Terri Meyer Boake）

At the time, Griffis included within his study concrete filled tube (CFT) systems, reinforced concrete (RC)/steel reinforced (SRC) systems, and reinforced concrete (RC)/steel reinforced concrete (SRC) wall systems. It is of interest to note that prior to 1994 when Griffis made his speech, there were only 53 composite structures of any height recorded in the CTBUH database, and all were in the United States.

The nature of this material shift must be addressed alongside the recognition of global preferences in construction methodology. Global trends must necessarily be aligned with access to materials and either the strengths or limitations of local expertise in the labor force.

CTBUH: Tall Buildings in Numbers

First Study on Materials and Systems

The CTBUH Journal 2010 Issue II "Tall Buildings in Numbers Report," the first to provide a comprehensive overview of changes in structural materials and systems, published data that indicated a very rapid decline in the choice of all-steel for tall buildings. Of the 100 tallest buildings constructed in the decade from 1960 to 1969, approximately 96% were "all-steel." This steadily dropped to reach only 20% in the decade spanning 2000 to 2010. Reinforced concrete went from 2% in the 1960 survey to almost 50% in the 2010 survey. Composite construction went from 2% in the 1960 survey to about 30% by the 2010 survey, surpassing steel. By 2015 all-steel represented only 11% of the world's 100 tallest buildings and was being chosen for only 3% of the 200m+ completions (Figure 2).

Shift from Steel to Composite

One of the issues with the term "composite construction" is that it encompasses a variety of ways to structurally combine steel and concrete. Whereas the term may have initially been primarily associated with steel framed buildings having a reinforced concrete core in a North American-dominated tall building scenario, as mentioned in the CTBUH definition, it has grown to include structural variations that, while maybe uncommon in North America, have come to dominate tall building construction in Asia and the Middle East. These systems include concrete filled steel tubes (CFT) and concrete encased steel frames. So the term composite, which five decades ago served as a "catch all" for buildings that did not belong in the major categories of all-steel or reinforced concrete, is now assuming a significant proportion of buildings on an annual basis. This has resulted in a dilution of accurate information in the database as the information about buildings has not been collected with any more specificity than whether it is "composite construction" of some sort. The ever increasing number of tall buildings that is being constructed annually is exacerbating this problem.

The Composite Project

As a user of the Skyscraper Center database as well as a recently appointed member of The Skyscraper Center Editorial Board and

演讲时，世界高层建筑数据统计中只有53座不受高度限制得复合结构建筑，并且这些建筑全部都在美国。

材料转变的实质与人们对某种施工方法的偏爱有必然的联系。全球发展趋势要么需要和人们获得材料的方法相契合要么和当地劳动力的优劣相匹配。

世界高层建筑与都市人居学会：高层建筑数据统计

材料和系统的首次研究

世界高层建筑与都市人居学会杂志2010年第2期刊载的《高层建筑数据统计报告》是对结构材料和系统改变的首次全面的研究，公布的数据表明高层建筑选择钢结构作为材料迅速递减。1960年–1969年的十年中，100所建筑中大约有96%是“全钢”建筑。但是在2000年到2010年间，这种情况逐步锐减到20%。钢筋混凝土材料的使用情况在1960年报告显示的2%，在2010年的报告中显示约为50%。报告还显示复合型建筑的数量在1960年到2010年间从2%上升到大约30%，已经超过了“全钢”建筑的数量。到2015年为止，世界前100座最高建筑中“全钢”建筑结构只占11%，在世界上高度超过200米的建筑群中只占3%（图2）。

从钢材料到混合型材料的转变

术语“复合型建筑”其中一点的争论是它包含了在结构上钢与混凝土结合的各种方式。在北美高层建筑方案中，“复合型建筑”最开始是与有钢筋混凝土核心筒的钢框架结构联系在一起的，正如世界高层建筑学会所定义的一样。复合型建筑现在已指多种结构型建筑，它在北美并不常见，在亚洲和中东颇受欢迎。这些系统包括CFT系统和钢骨混凝土框架。因此，复合材料在五年前作为高层建筑的“打捞

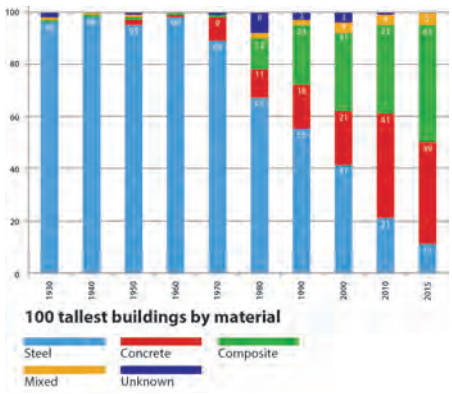

Figure 2. 2015 Year in Review from the Council on Tall Buildings and Urban Habitat showing the decrease in steel and increase in alternate structural systems for the world's 100 tallest buildings as a percentage of the total. (Source: CTBUH)
图2. 2015年高层建筑与都市人居学会表示：世界上100个最高建筑物减少使用材料和增加使用替代建筑结构系统及其在所有建筑物中的占比。（来源：CTBUH）

the CTBUH Height Committee, and with an interest in having a more accurate data collection system, I proposed a research project to assess composite buildings with the aim to create clearer and more closely defined terms that would be applied to the current buildings in the database to create more finely grained, accurate, information, and that would be used going forward to collect data in a more accurate manner if indeed the information was available.

A preliminary study of the data available from the CTBUH Skyscraper Center online database suggested that this incredibly recent and rapid shift towards composite construction could render the database diminished in terms of accuracy and depth if the definition and parameters of composite construction were not more clearly defined and applied as a categorized system in the near future (Figure 3). The initial basis of the composite type that reflected the North American deviation from all-steel, which is a concrete core with steel framing, may no longer be accurate. It was speculated as the starting point for the research that the predominant globally resultant categories would also include the use of concrete filled steel tubes as well as steel encased concrete. The study would also collect finer data on incidents of the use of diagrids, braced trusses, outriggers and megaframe systems.

This is the first study of its type to be done to both establish the nomenclature and definitions associated with composite structures as well as to study their global geographic distribution. The research was undertaken in summer 2015 with work ongoing to March 2016. The data analysis included in this paper reflects information to the end of March 2016. It was decided to limit the initial research to buildings of 150m+ as it was felt this would limit the scope of the initial work and provide adequate information to proceed with establishing the definitions of classification and a point from which to move forward. The use of composite is also more prevalent for taller skyscrapers.

The method was simply to search for construction images of the 582 composite skyscrapers (completed or under construction at the time of the study) whose height exceeded 150m in order to categorize them into the initially assumed three composite sub-types: concrete filled steel tubes (CFT), steel frame with reinforced concrete core, and concrete encased steel frame. The use of construction photos was adopted for the primary means of investigation for the following reasons: these could most easily reveal the construction method; are easily available online in several "fan-run" skyscraper forums; and, obtaining drawings and detailed information from architects, engineers and contractors would require more effort and was likely to be less time effective. As it was not the intention of the study to publish the images, copyright was not considered to be an issue. The initial research was conducted by Jasdeep Multani and Jeff So of the University of Waterloo, School of Architecture.

Accuracy and Completeness of the Data

Of the 582 projects, there were 79 for which construction images could not be found, providing us with an 86.4% success rate. The difficulty with finding information for the 79 projects seemed to be divided into buildings that were constructed "pre-internet" and those located in more remote cities where visitor access is less common, in particular third and fourth tier Chinese cities. The largest issues with insufficient data are as follows:

- China: 30 buildings
- Japan: 13 buildings
- United States: 12 buildings
- South Korea: 12 buildings
- Australia: 5 buildings
- Other countries: 7 buildings

工具”，并是全钢和钢筋混凝土的主要类别。而今，它正成为建筑中的主要材料。因此，这便造成了数据库中信息的不准确，因为关于建筑的信息的收集关注的不再是建筑本身的特点而是此建筑是否是“复合型建筑”。每年逐日递增的高层建筑更是加重了上述问题。

综合项目

作为摩天大楼中心数据库的使用者和新任命的摩天大楼中心编辑委员会成员与世界高层建筑学会高度委员会成员，我希望收集到更加准确的系统数据信息，同时我提议进行一项研究项目去评估复合型建筑，此研究项目的目的是创造更加统一、定义更加明确的复合型建筑。研究结果将会应用到当前建筑数据中去创造更准确无误的信息，如果信息可利用，此项项目还可以更加准确的收集信息。

对来自世界高层建筑学会摩天大楼中心的在线数据库的可用数据的初步研究表明：如果复合型建筑的定义和参数不明确并且在未来没有特定的系统，其最近迅速的转变会导致复合型建筑在精度和深度方面的数据库逐渐减小。反应北美不再使用“全钢”复合型材料的原始数据也许不再准确，其实这些“全钢”结构也是带混凝土核心筒的钢框架结构（图3）。但是这些最初的数据可以作为本次研究的起点，本次研究不仅对世界范围内的钢骨混凝土结构进行研究，还将对全世界的钢管混凝

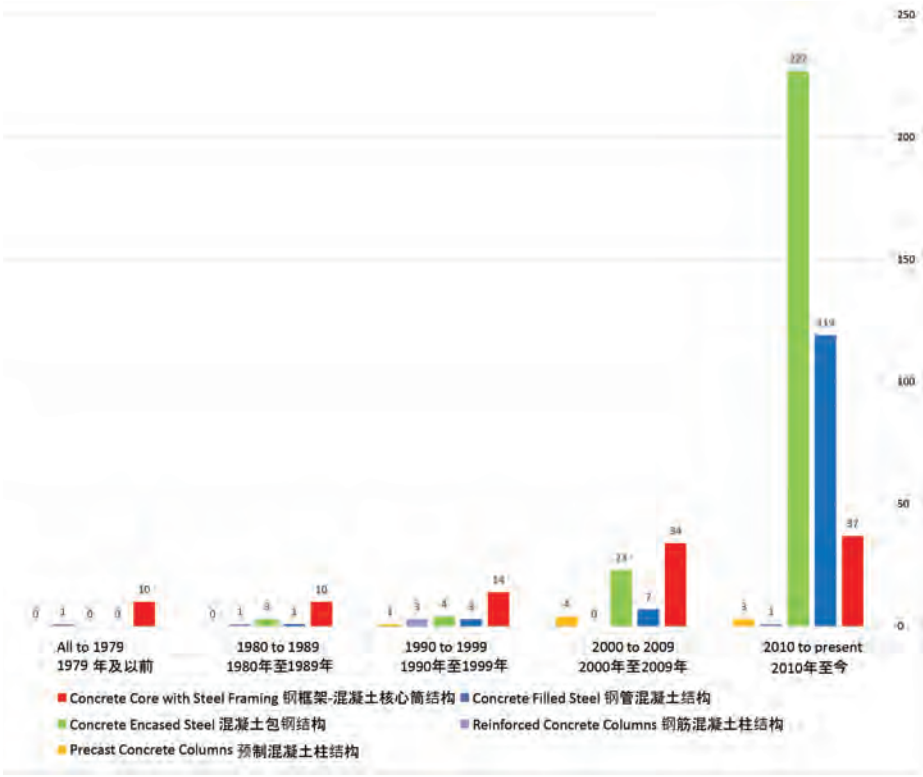

Figure 3. Data generated by the analysis illustrating the number of buildings 150m+ identified as composite construction that have been completed to 2016. (Source: Terri Meyer Boake)
图3. 数据分析表明，截止到2016年高于150米的复合型建筑的数量。(来源：Terri Meyer Boake)

Figure 4. The composite system comprised of a reinforced concrete core with steel framing for the columns and beams can be adapted to different forms. It is not confined to orthogonal construction. (Source: Terri Meyer Boake)
图4. 复合系统是由混凝土核心和钢框架组成，由此柱和梁结构可以有不同的结合形式。它不仅仅只适用于正交结构建筑。(来源：Terri Meyer Boake)

The number of projects that proved to have no images available, based on the year of completion, has risen in much the same proportion as the over number of composite buildings. The spike in numbers for completion dates of 2016 and beyond is not considered a problem as the likelihood of obtaining construction images for these projects is good, as projects studied prior to the installation of the enclosure systems had a higher success rate than already completed projects. As construction proceeds over the next year or so, it becomes more likely to find information about some of the missing buildings.

Preliminary Findings

The 503 projects with images and data were validated, and the results confirm much of the speculation about the state and evolution of composite construction as well as global realities concerning its spreading use.

It should be clarified that the major aspect of analysis, given that many projects may use complex variations of the systems, was to look primarily at the major structural system for the perimeter of the tower as the basis of the category decision. Buildings that use concrete filled steel tubes (CFT) for instance will often also have a reinforced concrete core. The focus was then on the nature of the column and beam system and not the specific structural relationship between the concrete and steel reinforcing in the core (Figure 4).

Five Primary Systems

The preliminary evaluation of typologies confirmed the existence of the three major anticipated categories and also was able to identify fourth and fifth minor categories comprised of "concrete columns with steel

土进行研究。而且，这次研究会对有关于编织网格结构，支撑桁架，悬臂以及巨框架系统的使用情况进行更加准确的数据收集。

以上是对复合型材料类型的首要部分研究，不仅包括地理分配的研究，还包括对其定义的明确。此次研究开始于2015年夏季一直持续到2016年三月份。本次发言所讲的数据同样反映了2016年三月末的情况。此研究将研究对象锁定为150米以上的高楼，因为这对对起初的研究工作做好限定，并且能够为不同类型建筑的定义工作和继续发展提供足够的借鉴信息。复合材料的使用也会在高层建筑中使用更加广泛。

初步研究方法是收集582所高层建筑的图片，这582所高层建筑图片包括已经建成的和在建的，并且这582所高楼的高度都是150米以上，这是为了给他们分别归入三种最原始的复合材料类型中：钢管混凝土结构（CFT），钢筋混凝土核心筒–钢框架混合结构和钢骨混凝土框架结构。建筑图片的应用是本研究的主要研究方式，有如下几个原因：1.因为通过图片能更容易地看出结构方式；2）通过几个“风机运行”的高楼峰会论坛，可在在线获得图片；3)同时从建筑师、工程师、和承包商那里获得图纸和详细信息可能需要付出更多的努力而且可能需要更多的时间，而效果也可能不是很好。虽然研究本意不是公开图片，但版权不是问题。最初的研究是由滑铁卢大学建筑学院的Jasdeep Multani and Jeff 指导进行的。

准确和完整的数据

582个项目中有79个项目的建筑图片无法找到，这给我们提供了86.4%的成功率。79的建筑项目信息寻找的困难一方面是那些如同建设“前互联网”的建筑，另一方面是坐落于游客罕至边远城市的建筑，尤其是中国的三、四线的城市。信息不足的最主要的几个国家如下：

- 中国：30座建筑
- 日本：13座建筑
- 美国：12座建筑
- 南韩：12座建筑
- 澳大利亚：5座建筑
- 其它国家：7座建筑

那些证明没有可用图片的建筑，以竣工之年为基础，在数量上已经上升到与复合型建筑的数量相一致的程度。

2016年或者2016年之前的数量激增不是问题，因为获取建筑图片的可能性就如同在围护系统在完全建造好之前就已经取得了很高的成功率一样。随着复合型建筑在未来几年的建造进展，一些仍然未知的建筑的信息也将会一一浮现。

初步调查结果

503项带有图片和数据的项目已经验证，结果不仅使复合型建筑全球性地广泛存在的推测得到了证实，而且人们对其形式和演变的推测也得到了证实。

如果很大一部分项目使用种类很复杂的系统，那么研究分析的主要方面就是将塔的周边结构系统作为分类的主要依据。例如，使用钢管混凝土（CFT）作为结构形式的建筑通常也会使用钢筋混凝土核心筒。关注点在柱梁系统而不是核心筒内的混凝土和钢筋的结构关系（图4）。

五个主要系统

类型的初步鉴定证实了三种预测类型的存在，也同样确实了三种类型下面第四种和第五种更精小的类型，即“混凝土柱与钢梁”和“预制混凝土柱与钢梁”。虽然这种建筑结构类型的例子不常见，但是材料复合使用的本质具有很大的不同并且可以追本溯源。吉隆坡的双子星塔就是用混凝土柱与钢梁建造的。日本的住宅楼建筑项目使用预制系统的数量也有上升。

也存在许多项目用一些不同寻常的高度复杂的方式使用钢铁和混凝土，并且这些方式也不属于以上提到的五种类型中的任何一种。虽然缺乏足够的技术信息以定义具体的结构体系，但是这些方式将仍然在复合材料类别的大范畴之下。

图5简单明了地展示了当前复合材料的使用情况，包括所有过去所有高于150米高层建筑。钢骨混凝土结构与其他类型的钢管混凝土更占主导地位，这表明它比传统钢筋混凝土核心筒–钢框架混合结构在使用率上占更大比重。

复合结构与建筑高度的关系

虽然复合型结构建筑现在才兴起20年，但是复合结构建筑（所有类型）和建筑高度之间的关系的评估已经完成。

图6显示了建筑高度和复合建筑类型的关系。在150米至299米的高度范围内，混凝土包钢结构明显是主要的选择。超过300米的复合结构高层建筑数量相对较少，对于研究而言数据有限。

如果我们比较图7和图8，也包括其他框架系统（复合结构作为不可分割的范畴），我们可以看出“全钢”建筑的数量已经下降，而当我们大体数一数大于150m的建筑的时候，钢筋混凝土材料已经占据主导地位。造成这种情况的部分原因是（这些建筑）以非西方国家为主并且大批居民建筑和酒店大楼为了与写字楼使用率想匹配通常选择钢筋混凝土作为建筑材料。来自CTBUH的数据显示了这种偏爱。不过，当我们把目光投向超过300m的超高层建筑时，会发现它们更倾向于使用复合结构体系。

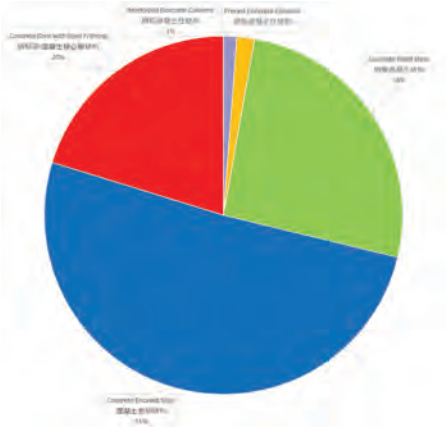

Figure 5. Global percentages of composite use in all buildings over 150m. (Source: Terri Meyer Boake)
图5. 所有高于150米的高层建筑中复合材料全球所占比例。(来源：Terri Meyer Boake)

beams" and "precast concrete columns with steel beams." Although instances of this type of construction were sparse, the nature of the composite use of the materials is significantly different and seemed to warrant tracking. Reinforced concrete columns with steel beams were used in the construction of the Petronas Towers in Kuala Lampur, and the use of precast systems is on the rise for residential projects in Japan.

There were also a number of projects that were truly using steel and concrete in unusual and highly complex ways that clearly did not fall in any of the 5 categories. These will remain under the general composite category, as will all buildings with insufficient technical information to define a more particular system.

Figure 5 represents a snapshot of the current state of composite use that includes all 150m+ buildings ever constructed without indicating changes over time. There is a clear dominance of concrete encased steel over the other types with concrete filled steel tubes representing a larger proportion than the concrete core with steel framing, which had been the traditional dominant application of this type.

Relationship Between Composite and Building Height

As composite construction has only surged in the last 20 years, an assessment of the relationship between composite construction (all categories) and building height was done. The reasons for the development of tall building systems varies, but height has always been a driving factor for innovation as it challenges the ability of the building to resist lateral loads from wind and seismic events.

Figure 6 illustrates the main findings of the analysis in terms of the relationship between building height and the choice of composite system. There is clearly a preference for Concrete Encased Steel overall, but with a dominance in the 150m to 299m range. The quantity of composite buildings that exceed 300m is substantially lower, providing a more limited data set for study.

If we compare Figures 7 and 8, also including the other structural systems (with composite as an undivided category), we can see that the use of all-steel for tall buildings has dropped, and that reinforced concrete has taken a

如果2014年至2015年的数据足以真实地呈现某种趋势，那就比较其他建筑方法越来越多的超高塔相都会将其建造成复合型建筑。

地理区域决定的复合类型

仅仅是从有趣的方面讲，研究中存在一种观念，即复合型建筑的喜爱和使用仅仅在中国和其它亚洲国家存在。钢骨混凝土框架在亚洲地区的选材上占主导地位的数据的确证明上述是对的。CFT和钢骨混凝土框架在北美和欧洲市场的确是使用率较低。一些地区几乎不使用此类建筑材料。

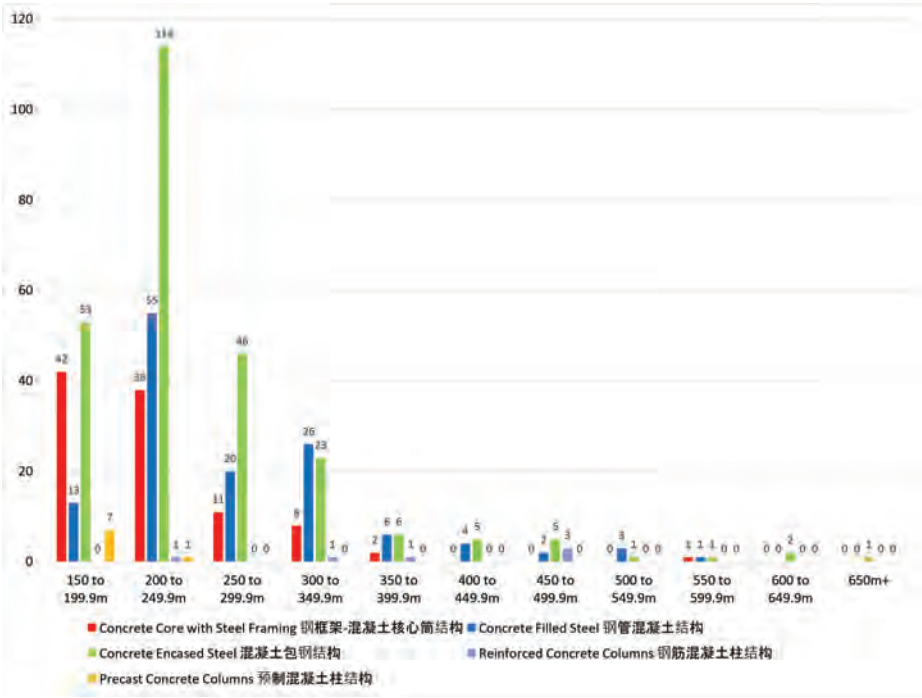

Figure 6. The Relationship between Height and Composite Type All Dates. (Source: Terri Meyer Boake)
图6. 各时期建筑高度和复合建筑类型的关系。（来源：Terri Meyer Boake）

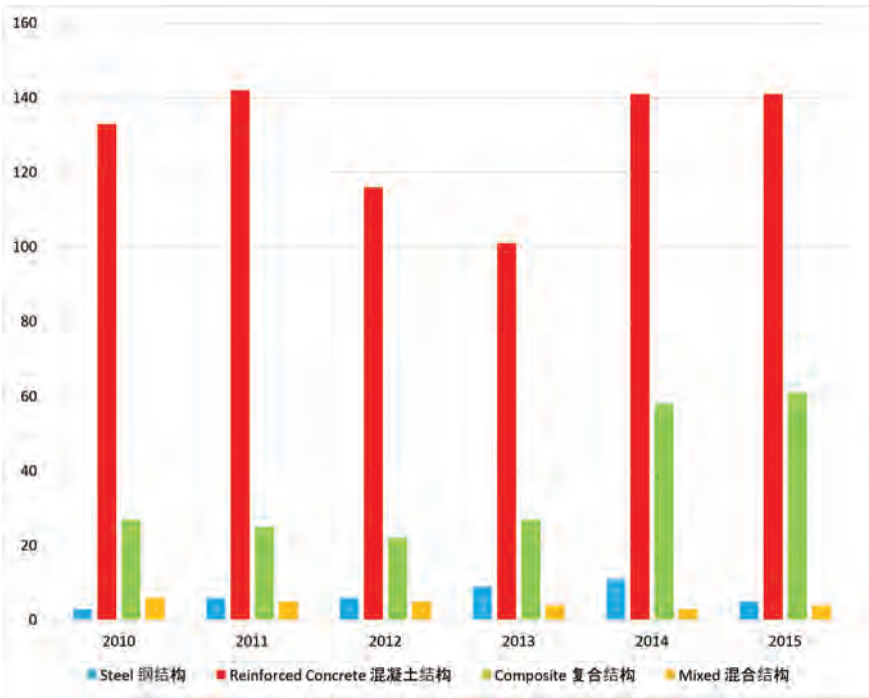

Figure 7. All buildings completed over 150m by construction type. (Source: Terri Meyer Boake)
图7. 150米以上不同结构类型的建筑。（来源：Terri Meyer Boake）

dominant role when looking at buildings over 150m in general. This is due in part to the dominance of non-Western countries as well as to a surge in the construction of residential and hotel towers that tend to use reinforced concrete for its suitability to these uses over office occupancies. Data from CTBUH shows this preference. However when we look at Supertall towers (300m+), there seems to be a trend towards the use of composite systems.

For Supertall towers there is an increasing trend towards composite construction over all other methods if the statistics from 2014 and 2015 indeed represent a trend. Information yet to be analyzed from the project will look to discern how other methods of assisting with height have figured into this scenario, including the use of outrigger systems, megacolumns and megaframes.

Composite Type by Geographic Region

There was a sense going into this study, based purely on anecdotal evidence, that it would show a clear preference for the use of composite construction in China and other Asian countries. This was proved true by the data with concrete encased steel framing clearly dominating the choice of type in Asia. The incidents of CFT and concrete encased steel frame systems are absent or low in the North American and European markets. Some markets show very little use of composite systems altogether. There were no composite buildings in the 150m+ range in South or Central America where reinforced concrete construction remains dominant.

Figure 9 shows the clear preference for composite construction in Asia, as well as its domination over the construction of tall buildings in general. Figure 10 shows the preferences within composite types by region. As a percentage of the whole, Asia has the least incidence of concrete core and steel frame, with North American and Europe revealing the opposite.

This information needs to be integrated with the balance of data pertaining to the uses of all-steel and reinforce concrete systems to result in a clearer understanding of the impact that the various composite systems are having on the local situation.

Of note, the use of a precast column system in combination with steel framing is a distinctly Japanese invention. This method of construction is being adopted for residential towers and also includes some significant seismic resistance elements.

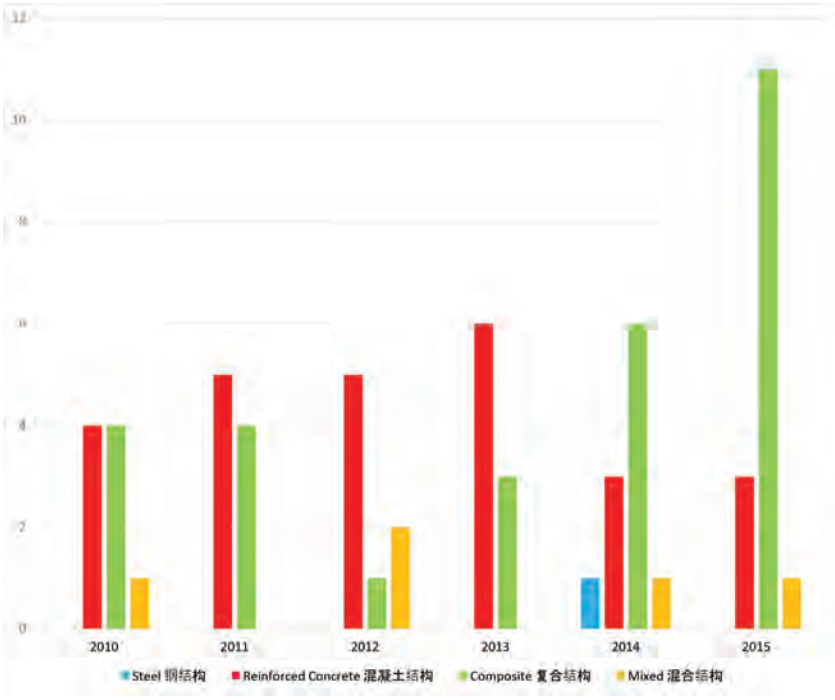

Figure 8. Buildings completed over 300m by construction type. (Source: Terri Meyer Boake)
图8. 300米以上不同结构类型的建筑。（来源：Terri Meyer Boake）

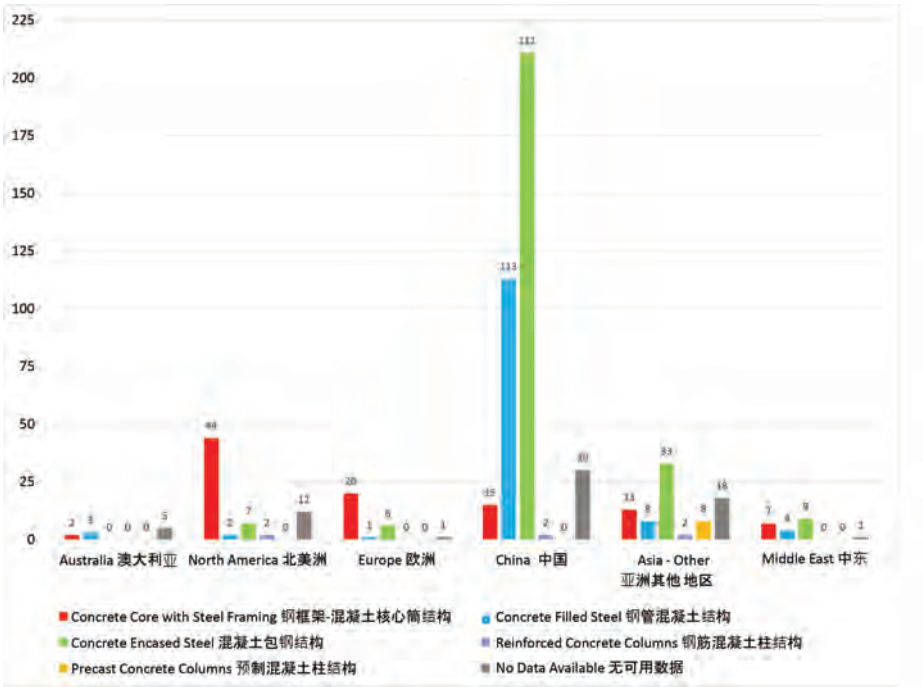

Figure 9. Breakdown of composite type 150m+ all dates by region. (Source: Terri Meyer Boake)
图9. 各时期不同地区150米以上复合结构建筑分类。（来源：Terri Meyer Boake）

Global Trends

Differentiated Skills and Preferences

There are varying reasons for global trends in the construction industry. When it comes to steel construction there are different factors that will impact the choices. This accounts for the "business as usual" model that seems to maintain current practices in North America and Europe as these areas are working within traditional trades, unions, practices and expertise. There has long existed expertise in the construction of all-steel, steel frame

在南美和中美洲国家高度超过150米的建筑，没有一座是使用复合型结构，这些地区仍主要使用钢筋混凝土结构。

图9不仅充分显示了复合型结构在亚洲高层建筑中的主导地位，也反映了亚洲地区对复合型结构使用的偏好。图10显示了不同地区对不同复合型结构使用的偏好。整个亚洲只有百分之一的地区会使用混凝土核心筒和钢架，而北美和欧洲呈现的恰恰相反。

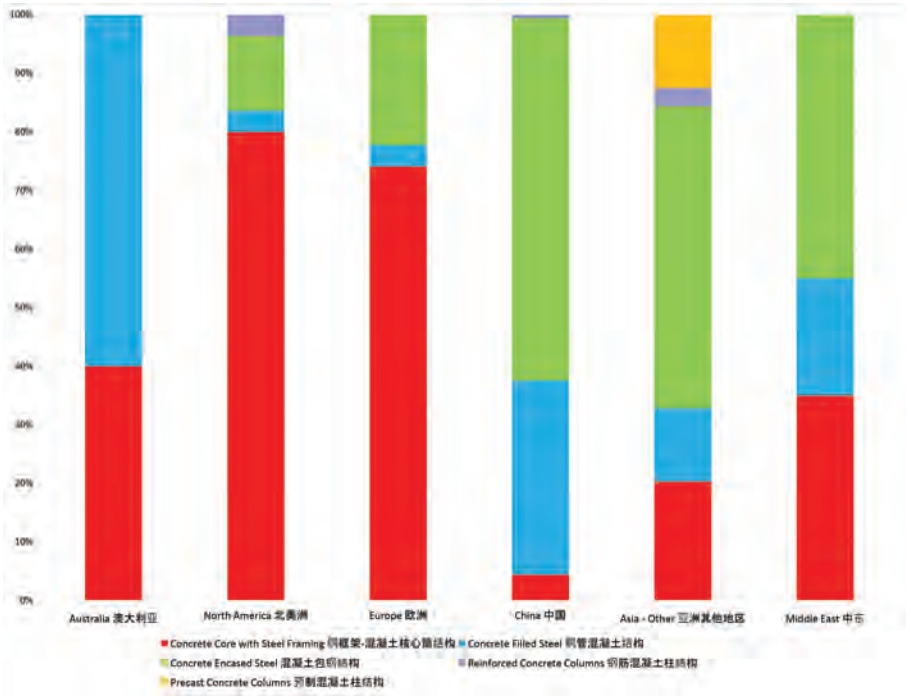

Figure 10. Breakdown of composite type 150m+ all dates by region, shown as a percentage of composite use. (Source: Terri Meyer Boake)
图10. 各时期不同地区150米以上复合结构建筑分类及复合结构使用占比。（来源：Terri Meyer Boake）

with concrete core and reinforced concrete buildings (Figure 11).

The North American and European steel industries have a preference for the use of hot rolled sections for concealed structural work which are widely available. Tubular steel (HSS) is also widely manufactured but seldom used in the construction of tall buildings. In addition there is a segregation of work that sees welding operations taking place in the shop and bolting operations taking place on site. This also holds for the Australian market. This is due in part to labor rates as well as to concerns for safety. The risks of working at height are of significant concern and this often precludes extensive welding at height. Although China encompasses many climate zones, the predominant areas of development experience little to no snow, making site welding less difficult. Climate therefore impacts Western preferences towards on-site bolting as the construction of climate control enclosures for welding operations at height adds significantly to the erection costs of the project as well as will result in delays.

The most interesting case, and one that is beginning to show a reverse global effect is the singular project in the United States that was found to be using CFT. The Wilshire Grand Center in Los Angeles, CA is not coincidentally being constructed by a South Korean owner who is working with a structural engineering firm, that although North American, has considerable experience designing composite towers for the Asian market.

Conclusions

The important takeaways from the preliminary findings from this study have much to do with creating a clearer picture of tall building structural systems as they are, as well as what this means for future design. As this industry is increasingly global, as indicated by the number of architecture and engineering practices with internationally scattered offices, we are seeing an unprecedented need to understand local construction techniques and preferences. Many firms that are based in Europe or North America where construction

此信息应该和有关全钢和钢筋混凝土系统使用有关的数据平衡地结合，目的是能够清楚了明白各种复合系统对当地实情所产生的影响。

预制柱系统与钢结构结合使用最著名的是日本的发明。此建筑方法用于高层住宅楼的建造以及还主要用来抗震。

全球趋势

不同技术和偏好

全球趋势在建筑行业中的形成有很多原因。当提及钢结构建筑，有许多影响着人们选择的因素。这种“一切照旧”模式似乎在北美和欧洲仍维持着当前的做法，因为这些地区都是在传统老工业、工会、实践和专业知识的背景下进行运作的。“全钢”建筑、钢筋混凝土核心筒–钢框架建筑以及钢筋混凝土建筑在建筑行业的专业知识早已在建筑行业形成（图11）。

北美和欧洲的钢产业更加偏向于对广泛可利用的隐藏框架工作进行热轧操作。HSS也被大批量生产但很少被用在建筑行业。同时，分隔作业是必要的，焊接作业应在工厂中而螺栓作业应在现场。这对澳大利亚市场也同样有效。这不仅是出于对安全的考虑，同时在一定程度上也是对劳动力的考虑。在高处作业的隐患是十分令人担忧的。虽然中国包含了许多气候带，但是主要发展地区是很少有雪覆盖的，这就是焊接作业少了很多困难。因此，气候使西方国家更加偏向于现场螺栓。因为对高空焊接所建的气候控制场很大成分上不仅仅造成了延期还增加了项目的花费。

Figure 11. Concrete filled steel tube systems as constructed in China require a very high amount of site welding that would be unusual in Western markets. (Source: Terri Meyer Boake)
图11. 钢筋混凝土系统想要在中国实施要求一定数量的现场焊接技术，这对于西方市场来说是不寻常的。（来源：Terri Meyer Boake）

practices still follow more traditional methods such as all-steel and steel frame with a reinforced concrete core, must come to terms when making proposals in Asia and the Middle East where there is a clear preference for the use of steel in composite systems such as concrete encased steel frames and concrete filled steel tubes. This fact must necessarily influence the overall design of the building and will be reflected in the detailing, cladding attachment system and the ability to adapt to desired forms. Education may need to be examined towards including more globally critical practices as these are not widely included in university level curricula in many Western countries.

Where to this point in time, at least from the exterior, there has existed a visual consistency in the outward appearance of skyscrapers that has tended to acknowledge their Western roots, this remarkable shift in structural systems is pushing the design of skyscrapers into new possible directions, from the inside.

Acknowledgments

I would like to thank several members of the Council on Tall Buildings and Urban Habitat for their assistance with this project: Antony Wood, Steven Henry, Aric Austermann and Marshall Gerometta. Their continued support will be essential to bringing the revisions to the data collection to the public.

Thank you to Mr. Zhi Gao of Architects Crang and Boake Inc., Beijing Office for the translation of the paper.

令人最感兴趣的的例子，并且这个例子已经开始显示出相反的全球影响是美国的某一单独的项目已经发现使用了CFT系统。在洛杉矶威尔希尔大中心,虽然北美已经在很大程度上对亚洲市场的复合型建筑进行了设计，而且南韩的经营所有者正与结构工程公司合作，但是CA系统并没有相应的使用。

结语

研究的初步发现提供的最值得借鉴的信息不仅仅关乎未来设计方式还与创造一幅清晰地高楼建筑系统的蓝图密切相关。由全球遍布建筑设计实践办公室表明，建筑产业逐渐成为全球性产业。我们将发现了解当地产业建筑技术和偏好具有史无前例的必要性。欧洲和北美建筑仍然更偏向于使用传统建筑方式，例如“全钢”建筑和“钢筋混凝土核心筒–钢框架”建筑。存在于这些地区的建筑公司，在对更偏向使用“钢骨混凝土”和“钢管混凝土”亚洲和中东地区进行建筑提案是，必须达成某种建筑协议。它必然会影响的建筑行业的总体设计，并且在细节设计、维护结构的连接系统和适应所需形式能力方面更有所体现。包括全球性重要实践方面的建筑教育需要再仔细审视，因为在许多西方国家，这并没有被广泛纳入大学基础课程。说到这一点，至少从外部看，高层建筑的外表具有视觉上的一致性，这也表明他们是从西方发展而来。从内部结构，结构系统的巨大转变加速高层建筑从全新视角进行设计的可能性。

致谢

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