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Façade Construction in China: Journey to Lean Design

中国幕墙建造：精益设计之旅

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Prior to joining Gensler Chicago, Allan Chung was an associate at Goettsch Partners with over 11 years of experience. Given his technical focus, he serves as a project architect, working on various high-rise office, hotel and mixed-use developments, plus the design and detailing of those building enclosure systems throughout China, such as the 40-story Nexus Center office building in Beijing; a 200-meter-tall residential tower in Tianjin. Recent projects in Gensler include a nine-story contemporary office building retrofitted from an existing structure in Chicago's West loop, and a 480,000 sqft Northwestern Medicine Lake Forest Hospital, 35 miles north of downtown Chicago.

加盟芝加哥Gensler前，艾伦是美国gp建筑事务所的理事，拥有超过11年专业经验。他专注于技术，并担任项目建筑师，致力于各种在中国的高层办公、酒店和混合式项目的发展，同时对相关建筑外墙系统进行设计和深化，如在北京的40层的嘉盛中心办公大楼;天津的200米高住宅塔楼。最近在Gensler的项目包括有在芝加哥西环区从一座现有结构翻新为9层高现代办公大楼，与及离芝加哥市中心35公里的480,000平方英尺的西北医学湖林医院。

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Dr. Ivan Mutis' work focuses on understanding the complex social nature of civil and construction projects through theories, tools, and methods to achieve high project-performance through information technologies. He investigates the ability to improve the effectiveness and efficiency of associated processes such as project design, construction, and sustainability by focusing on social systems, technological tools, and the natural environment of the project. Dr. Mutis' interest is on studying more effective means of collaboration and communication of project information by working on areas such as natural language processing, information retrieval, social networks, and organizational theories.

穆迪斯博士的工作是通过理论、工具和方法专注了解土木工程与建造工程项目的复杂社会性质，并通过信息技术以实现高效项目特性。通过关注社会系统、技术性工具与及项目的自然环境，他在考察关联进程的有效性和效率的改善能力，如项目设计、施工和可持续发展。穆迪斯博士的兴趣是透过攻读自然语言处理、信息检索、社会网络和组织理论等领域，来研究项目信息合作与沟通的更有效方式。

Abstract | 摘要

There is a recent trend in the construction industry to implement "lean concepts," a management strategy based upon the Toyota Production System philosophy. While the construction industry mainly focus on lean strategy for production in both the shop and field environments, there are also opportunities to apply the concept during the production of designs, such as façade design and production processes, where the façade design and consultant team convey their methodology of quality assurance and quality control (QAQC) into the process. However, to overcome new challenges posed from overseas projects, foreign design teams need to evolve their conventional QAQC systems and procedures in order to enhance the architectural product quality through long distance operation and oversight. This evolution of traditional standards and workflows resembles the lean strategy, resulting in a win-win condition for both the foreign design team and the local façade subcontractor, thus delivering a more successful project.

Keywords: Building Enclosure, Façade, Lean Construction, Lean Design Management, Quality Assurance, Quality Control

建造业近来有一个趋势实施"精益概念"，是依据丰田生产系统哲学为基础的一个管理策略。而当建造业将精益策略在多数情况下集中在厂房与工地环境的生产时，有关概念也有机会应用在设计制作上，如外墙的设计与制作过程，当中外墙设计与顾问团队在过程中传达了其质量保证和质量控制（质检）的方法。然而，要克服从海外项目带来的新挑战，外国设计团队需要进化其常规质检系统和程序以加强通过远距离操作和监督的建筑产品质量。这种在传统标准和工作流程上的演变与精益策略类似，通过实现一个更成功的项目，从而对外国设计团队与当地外墙分包商造成双赢的局面。

关键词：建筑外墙、幕墙、精益建造、精益设计管理、质量保证、质量管理

Introduction

In 2014, Chicago Tribune architecture critic Blair Kamin published an article series, "Designed in Chicago, Made in China," reviewing the rapid urbanization of China and the role Chicago architects played in the expansion. Modern China's urban population growth has benefited from the Chinese economic reform which began in the late 1970s, with the inflow of foreign investment toward the first tier cities – namely Beijing, Shanghai, Guangzhou and Shenzhen. Shenzhen for example, went from a sleepy border town of 58,000 in 1980 to a sprawling urban metropolis of more than 10 million today (Kamin 2014).

To better visualize the urbanization growth, two timelines of building comparisons have been generated from the CTBUH's Skyscraper Center online database between China and United States, from 1985 to 2014. Figure 1 is the comparison of 100+m (330+ft) buildings, and Figure 2 is 150+m (490+ft) buildings (Figure 1 & 2).

引言

2014年，芝加哥论坛报建筑评论家布莱•尔卡明（Blair Kamin）发表一篇文章系列"芝加哥设计，中国制造"，回顾中国的快速城市化与芝加哥建筑师在其中作发挥的作用。现代中国城市人口的增长始于20世纪70年代后期中国经济改革，受惠于外资向一线城市的流入–即北京，上海，广州和深圳。以深圳市为例，从一个在1980年为58,000人口的边陲小镇至现今超过1,000万人口的一个庞大大都市(Kamin 2014)。

为了更好地形象化城市化的发展，两个时间表来自于CTBUH的在线数据库，从1985年到2014年中国与美国两地建筑物的比较。 图01 是100米（330英尺）以上的高层建筑比较， 图02 为150m（490mg英尺）及以上的高层建筑（图1、2）。

时间表反映了在当时全球经济的影响下，展示了两国高层建造的显著差异。确实地中国的复苏步伐比较快，主要是因为新兴工业化国家的本质，并有以下的附助：来自地方政府的需求和参与，有竞争力的劳动力价格，以及外资的注入，以减少因世界各地的经济衰退对他们所带来的损失。

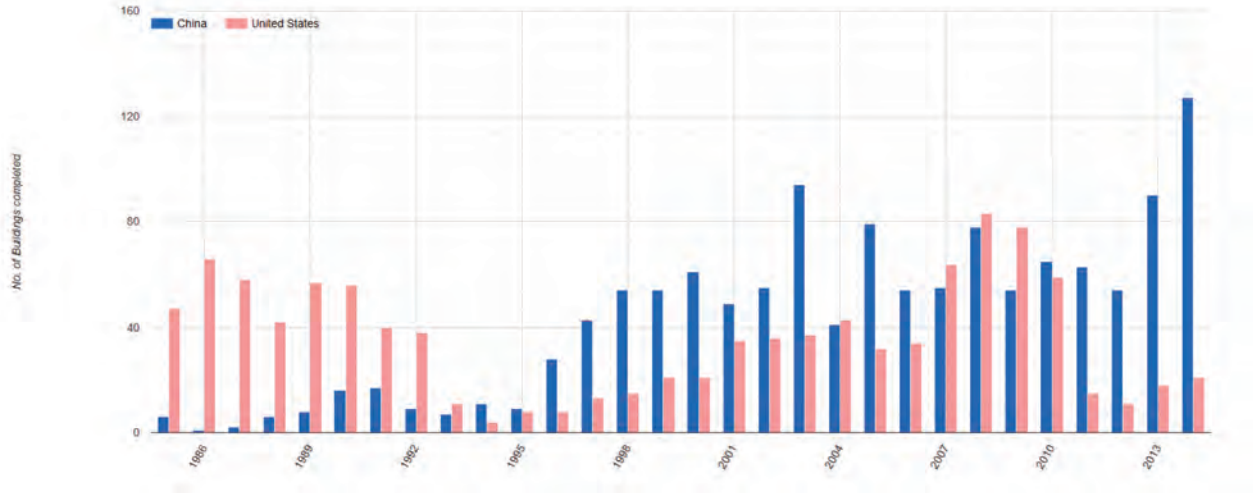

Figure 1. Comparison of completed tall buildings 100m or above between China and United States (Source: The Skyscraper Center interactive data, June 2015) (Source: Allan Chung)
图1. 中国和美国100米或以上已完成高层建筑比较（来源：高层建筑中心互动数据，2015年6月）（来源：艾伦钟）

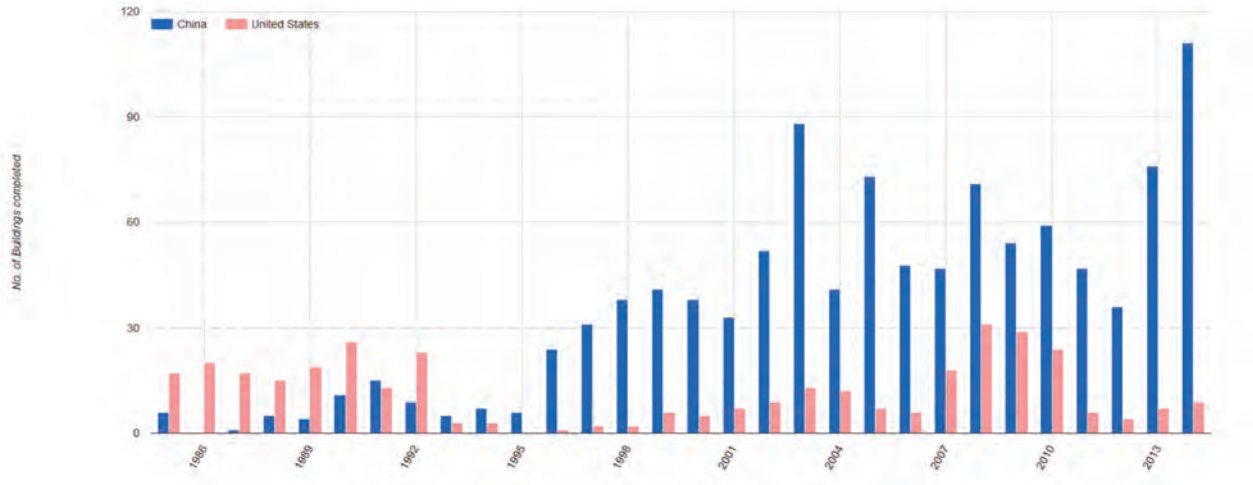

Figure 2. Comparison of completed tall buildings 150m or above between China and United States (Source: The Skyscraper Center interactive data, June 2015) (Source: Allan Chung)
图2. 中国和美国150米或以上已完成高层建筑比较（来源：高层建筑中心互动数据，2015年6月）（来源：艾伦钟）

The timelines reflect the consequences of the global economy at the time and illustrate a dramatic discrepancy in high-rise construction between the two countries. It is evident that the recovery pace in China is quicker, mainly due to the nature of the newly industrialized country, plus the following enhancements: demand and involvement from the local governments, competitive labor rates, and the investments inflow from foreign investors to minimize their damages from the recessions around the world.

In order to keep up with the country's economy growth, Chinese developers brought in architectural talent from overseas and learned insights from these experts on subjects including architectural aesthetics, allocation and layout of the programming and functions, and façade design and detailing. Contrarily, there are also learning curves for those foreign design teams to fulfill their design and ideas in China. Like other foreign companies in China, architects often struggle to realize their ambitions (Kamin 2014).

This paper focuses on the study of quality assurance and quality control (QAQC) execution in façade designs and productions that were developed by a Chicago architectural firm compared with the finished products that were built and installed in China.

Successfully executing façades requires numerous design and engineering contributions, with multiple trades for production and assembly, which require extensive and sustained coordination efforts. It is one of the architectural components that require substantial amounts of time and effort to document the component relationships. Unlike old solid masonry walls, which required tight tolerances (the interdependence of the components were less sensitive for interfacing to adjacent material because of field installation flexibility), modern façade technology is more sensitive to design and construction mistakes (Pietroforte et al. 2012).

Design Process

Throughout the façade design process, there are several participants involved. Figure 3

为了跟上国家的经济增长步伐，中国开发商从国外引进建筑专家，并从这些专家中学习，包括建筑美学、策划及功能的配置与布局，甚至外墙设计和细节深化。相对地，外国设计团队也有其学习曲线以在中国实践其设计和理念。像其他在中国外国企业，建筑师往往为实现自己的理想而挣扎(Kamin 2014)。

本文重点研究一个由芝加哥建筑事务所为针对建筑外墙设计与施工，且完成产品在中国生成及组装所制定的质量保证和质量控制（QAQC）的执行方式。

成功地制作外墙需要投入大量的设计和工程资源，并涉及多个行业参与生产和组装，是需要广泛和持续的协调。于建筑体系中它是其中一项需要大量时间和精力来记录组件关系。不像古老的砖石结构砌墙需要严格的公差，但因现场安装的灵活性，组件对毗邻材料对接的相互依存并不敏感，而现代外墙技术则对设计和施工失误极容易受到影响（Pietroforte et al. 2012）。

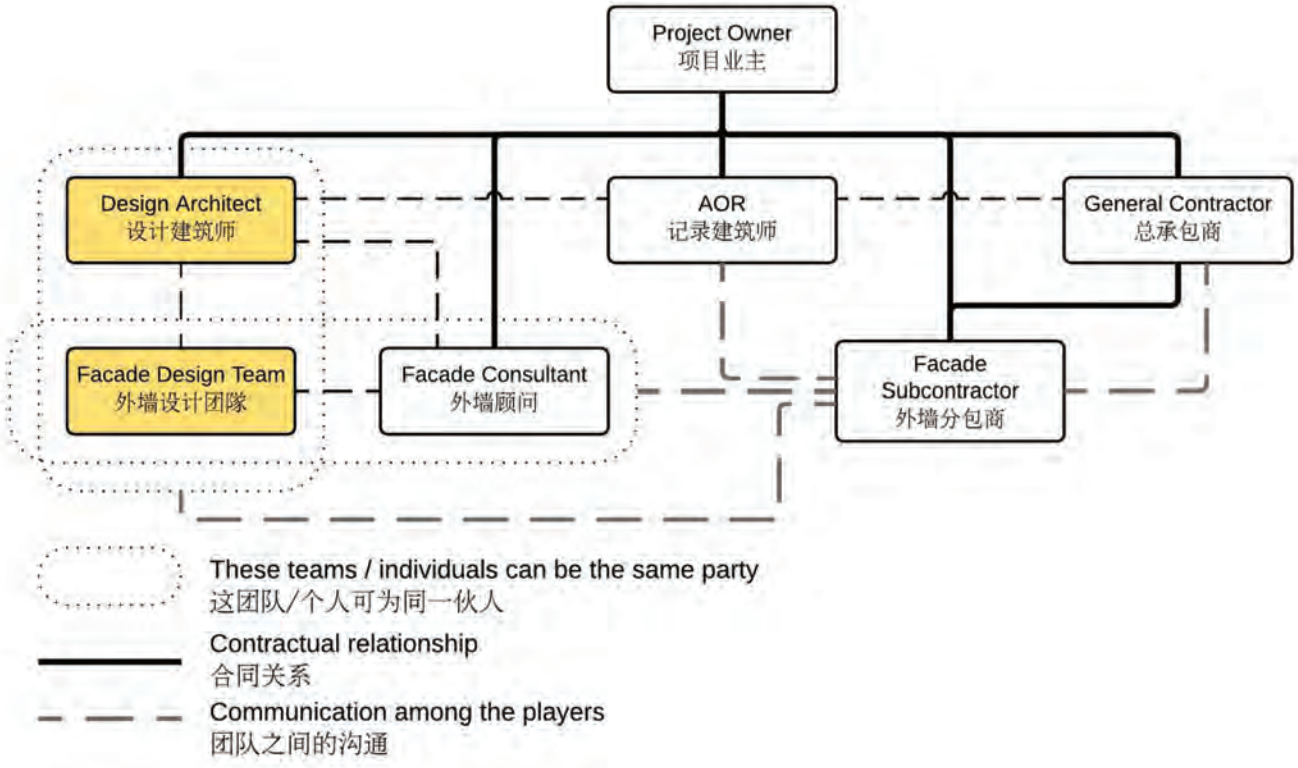

Figure 3. Example of typical Contractual relationships among the participants in the façade design process (Source: Allan Chung)
图3. 在外墙设计过程中各方参与者的典型合同关系例子（来源：艾伦钟）

shows an example of typical contractual relationships among the participants for executing façade design and production in China (Figure 3). The highlighted roles in the diagram indicate the group, the design architect, and their façade design team, which this research perspective is based upon, and also shows their QAQC on the façade design process, from the pre-construction phase to completion.

Building construction involves complex coordination among different teams with dissimilar perspectives. Per Oliveira and Melhado's (2011) research, table 1 identifies the generic activities and phases of façade design and production. Both the design architect and the façade design team have the responsibility to collaborate on all various requirements and document them in an organized manner. They also proactively review subcontractor documents and activities to ensure the design expectation can be executed properly in the construction phase.

The Façade Tender Package is a critical phase that, without this deliverable from the design team, ensures the construction stage cannot be executed effectively, as there is no designated benchmark for reference. It is a detailed documentation built upon existing information from the pre-design phase, which is included but not limited to the following requirements (Oliveira and Melhado 2011):

- Identify and define the criteria of the façade performance requirements,
- Define the façade systems and principal elements
- Document the composition of the façades, including definition of construction technologies,
- Preliminary list of interfaces, such as
- Interface with selected façade technologies
- Interface between the façade and the building mechanical systems
- Interface with design specifications (quality and performance)
- Interface with the means and methods of construction
- Graphically represent the adopted solutions with drawings
- Analyze the durability and maintenance issues of the selected façade system

The purpose of Façade Bid Package Review is to provide technical support for the project owner choosing the subcontractors by evaluating the comprehensiveness of the overall design and scope of work from their submission package. Figure 4 shows a generic

设计过程

在整个建筑外墙设计过程中，涉及各方的参与。图03 显示了一个在中国外墙设计与生成过程中各方参与者的典型合同关系例子（图3）。本文的研究是根据关系图中突显参与者，设计建筑师与其外墙设计团队，的角度对外墙设计过程执行他们的质检方式，从施工前阶段至完成。

建筑施工涉及不同团队有其各自观点的复杂协调。根据奥利维拉和迈尔哈多（Oliveira and Melhado, 2011）的研究，图表1 示明一般外墙设计与生成的活动及阶段。设计建筑师与外墙设计团队各有责任配合各方不同的要求，并有组织地将之记录。他们也主动地审核分包商的文件和活动，以确保预期设计在施工阶段中可以正确的实施。

外墙招标文件 是一个重要的步骤，如果没有设计团队在这方面的交付，施工阶段便不能被有效的执行，因为没有一个指定的基准作参考。外墙招标文件是一个详细文件建立在前期设计阶段的现有信息，包括但不限于以下（Oliveira and Melhado, 2011），

- 识别和确立外墙性能要求的标准，
- 确立外墙系统及主要元素
- 记录外墙的合成，包括施工技术的确立
- 拼接的初步清单，如:

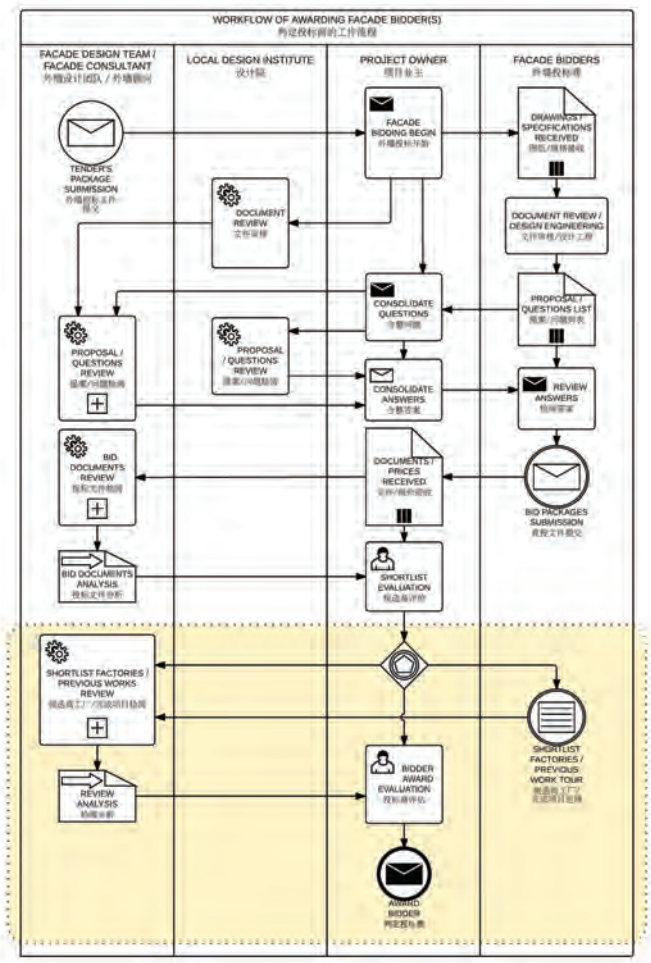

Figure 4. Workflow of awarding façade bidder(s) (Source: Allan Chung)
图4. 判定投标商的工作流程（来源：艾伦钟）

workflow of a bid review process for reference (Figure 4).

This process is usually done by an individual from the façade consultant team in order to maintain a relevant evaluation on the bidder's submissions and generate an analysis report through systematic evaluations based on the comprehensiveness of the information (Figure 5). Among 4 to 6 submissions, the consultant is able to recommend the top 2 or 3 bidders for owner's consideration.

Façade Shop Drawings Review is a critical process to evaluate the proposed engineering solutions, verifying the functionality and aesthetic character of the façade systems (Pietroforte et al. 2012). Shop drawings interpret and transform initial design drawings into detailed descriptions of construction processes and methods. They show instructions about the engineering of each component, such as attachment methods, fabrication and assembly with other components, plus method statements to explain the assembly and installation sequences. It requires a lengthy review process to determine if the subcontractor correctly understands the architectural design intents and can transfer them into workable shop drawings.

The Visual Mock-Up Unit (VMU) and Performance Mock-Up Unit (PMU) are physical full scale replica models that help all participants to understand the design proposal without misinterpretation. The VMU is more about aesthetic and visual control, which allows the owner and design team to verify cladding finishes in a full-scale perspective. Compared to the VMU, which is usually assembled with simulated framing elements, the PMU is performance oriented and composed of the actual project extrusions, which are approved after the shop drawing review process, in order to focus on the façade structural and thermodynamic qualities. The PMU test is a crucial QAQC

- 与所选择外墙技术的拼接
- 外墙与建筑机电系统之间的拼接
- 与设计规格（质量和性能）的拼接
- 与施工方法的拼接
- 图纸形式表达所采用的解决方案
- 分析所选择的外墙系统的耐用性和维护问题

外墙投标审核 的用意是为项目业主选择分包商提供技术支持，评估投标商所提交投标资料而判别其对整体设计和作业范围的全面性。图04 为一个投标审核的一般工作流程以供参考（图4）。

为了对投标文件作出一个中肯的评估，过程通常是由一个人来完成，通过系统的评估并跟据信息的全面性来做出一份分析报告（图5）。在4至6个投标文件中，顾问会推荐前两三位投标商给项目业主考虑。

外墙施工图审核 是一个关键的步骤来评估所建议的工程设计方案，验证外墙系统的功能性和外观效果的特性（Pietroforte et al. 2012）。施工图将原设计图纸解释并转化成施工过程和方法的详细描述。施工图显示出有关各组件的工程设计说明，例如附接方法，与其他组件的制造和装配，及次组件的安装，并加上方法陈述来解释组装和安装的次序。施工图需要一个冗长的审查过程，以确定施工单位正确理解建筑设计意图，并将之转化为具体实施的施工文件。

视觉模型单元（VMU）和性能模型单元（PMU）是实物足尺模型帮助所有参与人对原设计方案理解无误。视觉模型单元侧重于对审美和视觉的控制，这容许业主和设计团队通过足尺观点来验证外墙包覆饰面。相比通常以模拟框架元件来组装的视觉模型单元，性能模型单元侧重于性能并以实际项目的挤压构件来组成，是在施工图纸审核中已被认可的设计，以注重外墙结构和恒温特性。性能模型单元测试是质检程序中至关重要，以确保外墙系统实质上能够承受性能标准。

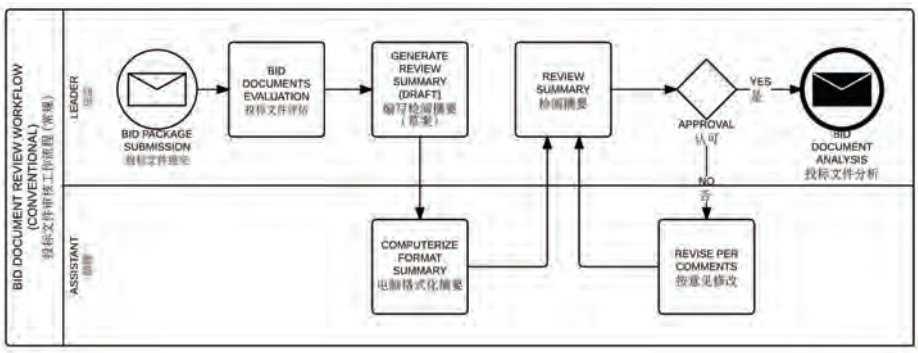

Figure 5. Bid document review workflow (conventional) (Source: Allan Chung)
图5. 投标文件审核工作流程（常规）（来源：艾伦钟）

procedure to ensure the façade system is physically able to withstand the performance criteria.

After the typical façade installation reaches a certain point, a Field Test will be performed with a high pressured water spray to several designated locations per specification requirements to test for leakage. The consultant will be present on the job site to witness the test to ensure the testing procedures follow the specified standard.

Observed Issues in the Process

When individual project participants work in geographical, social and cultural contexts that are both physically and figuratively distant from the context of the construction environment being developed, this can add considerable complexity to project collaboration (Jørgensen and Emmitt 2009). For projects in China, design architects must partner with an LDI who will be responsible for the construction documents. This causes fragments in the technical and management interfaces which frequently occur in façade design and production between the design team and the consultants, suppliers and contractors. Due to poor coordination between building systems and lack of direct communication between the project participants concerned in the design and construction processes, integration problems can occur and lead to major façade design failures, ranging from technical failures such as water leakages to disappointment in the realization of design ambitions (Oliveira and Melhado 2011). Depending on both parties' experiences, the run-in period of collaboration may vary, due to the following reasons:

1. Language and culture differentiation;
2. Lack of understanding of the project's local code;
3. Varying expectations/understandings of construction workmanship and methodology;
4. Vague scope of work;
5. Due to contractual scope of work, the LDI is not able to offer advice or preliminary service in advance;
6. Contrarily, follow-up service from the design team is limited by contract and fee;

These impact not only the schedule, but also the aesthetic and performance expectation of the project. Figure 6 highlights some common issues that the conventional QAQC procedures encounter in Chinese projects (Figure 6).

As architects reaching out for new client relationships with projects that are larger in size and taller in height, these new clients with their large construction business networks tend to prefer more subcontractors involved in the bidding process in order to select the best value, or even pick two to split the responsibilities in large scale complexes (Pietroforte 1995). This leads to the consulting team requiring more man-hours to review submittals in both the bid and shop drawing review processes, while the given timeframe to review is unchanged. And to make the

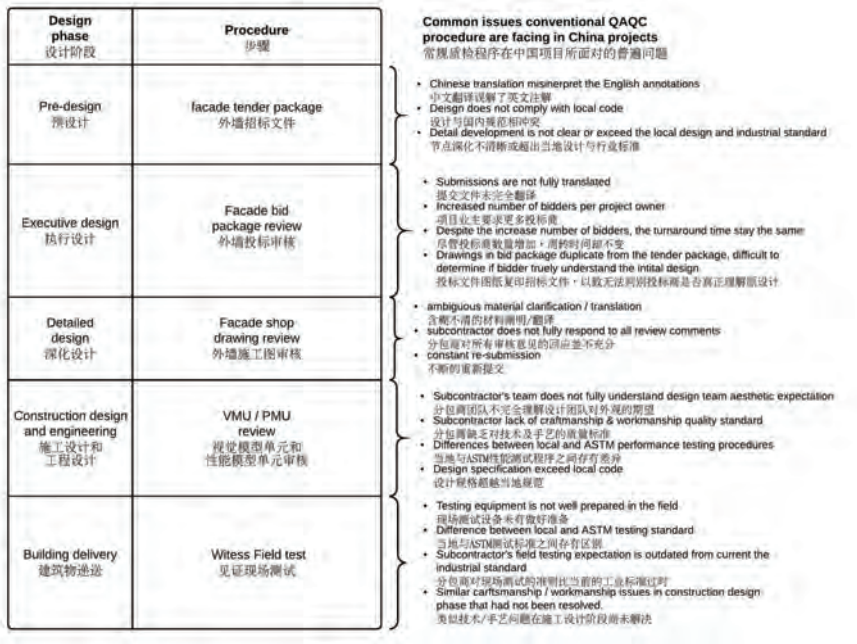

Figure 6. Common issues conventional QAQC procedures are facing in Chinese projects (Source: Allan Chung)
图6. 常规质检程序在中国项目所面对的普遍问题（来源：艾伦钟）

当典型的外墙安装到某一个点后，按规格要求会执行现场测试，将高压水喷淋至几个指定外墙地点进行泄漏测试。顾问会在工地现场目击测试，以确保测试程序按照规定的标准。

设计过程中被观察到的问题

个别项目参与者在地理，社会和文化背景等与被开发的施工环境实质的及比喻地分离，这样对项目协调增加会相当大的复杂性（Jørgensen and Emmitt 2009）。对于在中国的项目，设计建筑师必须与负责施工文件的当地设计院合作。这样的合作方式将设计团队与顾问，供应商和承包商之间频于外墙设计和生成出现的技术和管理拼接界面分裂。

在设计和施工过程中建筑系统之间贫乏的协调及项目参与者之间缺乏直接的沟通，可能会出现整合的问题，并导致严重的外墙设计失误（Oliveira and Melhado 2011），从技术失误如漏水或对实现设计抱负的失望。取决于双方的合作经验，合作的磨合期长短有所不同，并带有如下问题：

1. 语言与文化差异；
2. 对项目的当地规范要求缺乏理解；
3. 对施工手艺与作业方式的期望/理解有差异；
4. 模糊的作业范围；
5. 因合同上定了作业范围，当地设计院未能提前提供咨询意见或初步服务；
6. 相反地，因合同和费用的原因，设计团队的跟进服务受到了限制。

这不但对项目的进度有影响，同时也对项目的外观及性能期望有一定的冲击。图06重点介绍了传统质检步骤在中国项目所遇到的的一些常见问题（图6）。

当建筑师伸向带有更大更高项目的新客户关系时，这些新客户有他们自己庞大的建造业网络均倾向于更多的分包商参与了投标，来选择最佳的造价，甚至选择两个分包商于大型复合项目中分开项目责任（Pietroforte 1995）。这导致在投标和施工图审核过程均需要更多工时审核，但给于的审核时间却不变。更糟糕的的是，提交文件中没有英文翻译。

在施工图审核过程中，当提交图纸不符合设计要求时，重新提交是有需要的。遗憾的是，重新提交的图纸不一定解决所有审核意见，导致未解决的问题持续地在重新提交出现，主要原因有以下：

Phase 阶段		Processes 工序	Participants 参与者
Design Process 设计过程	Conceptual Design 概念设计	Preliminary Definitions / Creating the Product (Facade) 初步界定/创建产品 (外墙)	Project Owner | 项目业主 Design Architect | 设计建筑师 AOR | 纪录建筑师
		Briefing | 简介	
	Design Development 扩初设计	Preliminary Design | 初步设计	Project Owner | 项目业主 Design Architect | 设计建筑师 AOR | 纪录建筑师
		Pre-Design | 预设计	Facade Design Team | 外墙设计团队 Facade Consultant | 外墙顾问 AOR | 纪录建筑师
		Executive Design | 执行设计	
Preparation for Construction 施工准备	Construction Documentation 施工文件编制	Detailed Design | 深化设计	Project Owner | 项目业主 Facade Design Team | 外墙设计团队 Facade Consultant | 外墙顾问 AOR | 纪录建筑师 Facade Subcontractor | 外墙分包商
		Construction Design and Engineering 施工设计和工程设计	Facade Design Team | 外墙设计团队 Facade Consultant | 外墙顾问 AOR | 纪录建筑师 General Contractor | 总包商 Facade Subcontractor | 外墙分包商
Delivery | 递送		Planning for Construction | 施工规划	Facade design Team | 外墙设计团队 Facade consultant | 外墙顾问 AOR | 纪录建筑师 General Contractor | 总包商 Facade subcontractor | 外墙分包商
		Building Delivery | 建筑物递送	Facade Design Team | 外墙设计团队 Facade Consultant | 外墙顾问 AOR | 纪录建筑师 General Contractor | 总包商 Facade Subcontractor | 外墙分包商

Figure 7. Generic activities and phases of façade design and production (Source: Allan Chung)
图7. 一般外墙设计与生成的活动及阶段（来源：艾伦钟）

matter worse, there are no English translations in the submission documents.

In the shop drawing review process, resubmission is needed when the submittal does not meet the design criteria. Unfortunately, the resubmission may not necessarily address all the review comments, resulting in consistent re-submissions with unresolved issues, which is mainly due to the following:

- Inexperienced design team on the subcontractor side;
- The design team would not hire staff who can read and write the local language;
- The translation misinterpreted the English comments;
- The level of understanding to the issues vary;
- Subcontractors' excessive pursuit of profit.

The issues above require synergy between design teams and subcontractors to overcome.

Synergy and Strategies

As shown in table 1, there are several phases (highlighted) that were targeted in this study, where façade design and consultant teams are engaged in the design process and review the design proposal, evaluate details for refinement, and provide solutions to design errors (Figure 7). The teams apply and execute their standard QAQC practices to the project. However, for projects designed in the US and located in foreign country like China, the conventional QAQC procedures required further development utilizing the "lean principle" to implement new methods in order to meet the needs and overcome the barriers (Figure 8).

Lean construction is commonly known as the conversion of lean from production to construction. Lean production is based on

- 分包商一方缺乏有经验的设计团队；
- 设计团队没有雇用对当地语言有读写能力的员工；
- 翻译曲解了英文反馈原意；
- 在同一个问题上的理解水平不一致；
- 分包商对利润的过分追求。

上述问题需要设计团队与分包商协同克服。

协同与策略

如图表1所示，有几个阶段（已突显）为是次的研究对象，外墙设计和顾问团队在该设计过程中接合并审核设计方案，评估细节作进一步优化和对设计错误提供解决方案（图7）。团队对项目实施并执行他们的标准质检惯例。然而，对于在美国设计，身处外地如中国的项目，常规质检步骤需要进一步发展，采用“精益原则”（lean principle）实现新方法以满足有关的需要并克服有关障碍（图8）。

精益建造通常被认为是从精益生产转换致建造业界。精益生产的概念与实施是源于20世纪50年代丰田生产方式（Toyota Production System, TPS）。因战后资源极其有限，丰田开发出一套生产系统以增加效益。通过减少浪费，包括缩短前置时间，提高透明度，减少无价值附加活动，减少投入和输出的变动，平衡流动和转换活动的改良等原理来改善生产系统的设计与运作（Pestana 2014）。

虽然精益概念主要集中在施工现场及工厂建造活动，这些原则也适用于办公室的相关活动（Pestana 2014）。这研究集中在设计与文件记录阶段的精益方法，并随后将”精益文化”在机构中履行及于项目中发挥作用（Emmitt 2011）。

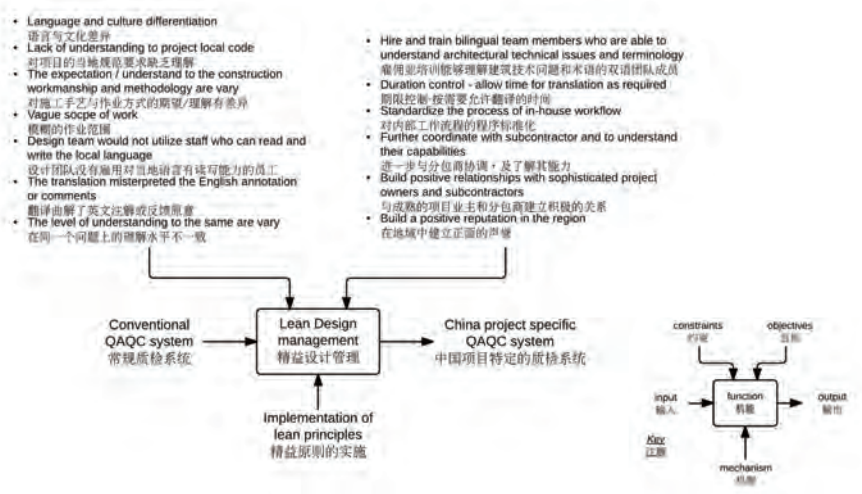

Figure 8. Lean concept implementation model for QAQC system (Source: Allan Chung)
图8. 质检系统的精益概念实现模式（来源：艾伦钟）

Design Phase 阶段	Activity 阶段	Constraints and Objectives 阶段	Lean Principles 阶段
Pre-Design 预设计	Issue Facade Tender Package 外墙投标文件	Define scope of work and building façade interface details using drawings of the facade systems and specifications. 采用外墙系统图纸和规格界定工作范围及深化建筑物外墙拼接节点。	#3, #5, #7
Executive Design 执行设计	Facade Bid Package Review 外墙招标审核	Evaluate facade subcontractor's bidding submission and provide an objective recommendation to project owner of the adequate bidder. 评核外墙分包商投标文件□给项目业主提供一个能胜任投标商的客观建议。	#1, #2, #6
Detailed Design 深化设计	Facade Shop Drawings Review 外墙施工图审核	The awarded contractor submit their drawings for approval. Consultant verifies if details are still correct according to the design and specification, whether the facade system interfaces are properly detailed, or the continuity of air / water and thermal barriers are being maintained. 中□承包商提交其图纸供审批。顾问核实如节点仍然正确的忠于原设计和规格，外墙系统拼接节点是否恰当的深化，或是否保持气/水密封与热保温层的连续性。	#1, #3, #7
Construction Design and Engineering 施工设计和工程设计	Visual Mock-up Unit (VMU) / Performance Mock-up Unit (PMU) review 视觉模型单元（VMU）和性能模型单元（PMU）审核	Verify any hidden issues before mass producing, using full size replica of a small portion of the actual building facade system(s). 采用实际建筑物外墙系统的一小部分的足尺模型，在大规模生产之前核实任何隐藏的问题。	#1, #3, #6, #7
Building Delivery 建筑物递送	Witness Field Test 现场测试见证	Witness and verify any water leakage or other issues in the final installation. 在最终安装中见证并验证任何水渗漏或其他问题。	#3, #6

Figure 9. The association of the Façade design and production process with lean principles (Source: Allan Chung)
图9. 外墙设计与生成和精益理念的关联（来源：艾伦钟）

the concepts and practices supported by the Toyota Production System (TPS) which was originated in the 1950s. Toyota developed a production system to be more efficient as resources were extremely limited after the war. The principles used to improve the design and operation of production systems by minimizing waste, includes reduced lead times, increased transparency, reducing nonvalue-adding activities, reducing variability of inputs and outputs, and balancing improvement of flow and conversion activities (Pestana 2014).

While the lean concept mainly focuses on the construction activities in the field and off site, these principles are also applicable to office-related activities (Pestana 2014). This research study concentrated on the lean approach to the design and documentation stages, and subsequently to the implementation of a "lean culture" in the organizations contributing to the projects (Emmitt 2011).

While lacking a universal definition, lean design in construction refers to approaches, principles and methods for managing processes of design and product development (Jørgensen and Emmitt 2009). Essentially, lean production systems consist of waste reduction and continuous improvement which can be applied to designs by conceptualizing design in three different ways (Tzortzopoulos and Formoso 1999):

- design as conversion of input to outputs – transform the perception of the client's requirements (inputs) into design decisions and actionable design documents (outputs),
- design as processing the flow of information – from various stakeholders to the designers and vice-versa,
- design as a process of value generating activities – identifying and eliminating nonvalue-adding activities in design.

Implementation of Lean Concept in Design Process

Practical considerations (Tzortzopoulos and Formoso 1999) that have been suggested to implement lean principles into architectural design and development process (Deshpande et al. 2012) are as follows:

1. identify and eliminate nonvalue-adding activities in design,
2. increase output value through systematic evaluation of client requirements,
3. reduce variability in the design process,
4. reduce approval cycle times for design documents,
5. focus on the complete design process using stage gates within design,
6. benchmark with other similar projects for systematic performance evaluation, and
7. build continuous improvement milestones in the design processes.

Figure 9 shows the association of the façade design and production process with the lean principles, according to the researcher's observations of the constraints and objectives for each design activities in the design phase, as identified in Figure 9. Further analysis below reveals how the processes are related with the lean principles (Figure 9).

The design documentation cannot be accomplished without the direct involvement

尽管缺乏普遍的定义，建造业的精益设计是指设计和产品开发中管理进程的途径，原则及方法（Jørgensen and Emmitt 2009）。本质上精益生产系统包括减少浪费和持续改进，并可通过概念化设计为三种不同的方法应用在设计上（Tzortzopoulos and Formoso 1999）：

- 设计作为投入转换为输出 – 客户需求的观念（投入）转换到设计决策和可执行的设计文件（输出），
- 设计作为流动信息的处理 – 从不同的利益相关者到设计师，反之亦然，与及
- 设计作为一个价值创造活动的处理 – 于设计中识别无价值附加活动并消除它们

在设计过程中精益理念的实施

以下实际的考虑因素（Tzortzopoulos and Formoso 1999）被视为精益理念，建议实施并融入建筑设计及深化过程中（Deshpande et al. 2012）：

1. 识别并消除在设计内的无价值附加活动，
2. 通过有系统的评价客户需求来增加输出产值，
3. 在设计过程中减少易变性，
4. 减少设计文件的审批周期，
5. 使用设计中的阶段途径来专注完成设计过程 ，
6. 为有系统的性能评价与其他类似项目衡量基准，与及
7. 在设计过程中建立持续改进的里程碑。

of a bilingual team member clarifying the drawings and specification with translation for the local bidders. As the process evolves, common design and material terminology has been standardized and consolidated where the English annotations are tied with the Chinese translations. This allows other team members to access and utilize the standard terminology into their drawings. This continuous process improvement (principle #7) helps to make the drawing production more efficient by minimizing variation and the transition time for translation.

The bilingual team members in the conventional shop drawing review process also help to refine the translation language to avoid comments lost in translation that lead to miscommunication and inefficiency in the resubmission.

To align with the lean concept, the process has been further adjusted:

- Identifying and eliminating nonvalue-adding activities in the design (principle #1) – instead of a consultant team leader following up the resubmission review, by providing an intensive review on the first submission, he or she is able to spreads out the work to apprentices and assistants to follow up the resubmission review based on previous comments with proper tutorial and communication, in order to minimize the manager's own time on the nonvalue-adding activities.

- Standardizing tasks in order to minimize approval cycle times for design documents (principle #4) – The cycle times of the procedure gradually improved from previous experiences once the team understands the "know-how" and the final output expectation; the lead-time of their part can be reduced.

- Standardization being the foundation for continuous improvement in the design processes (principle #7) – to further reduce lead-times and cycle times in the process, a list of standard review comments is developed and tied with proper translations into a spreadsheet. The director only needs to select the applicable comments and the report can be formalized by the assistant in a much quicker fashion.

With the increased bidders and timeframe constraint in the bid review process, assistance is necessary. Junior team members with extensive shop drawing resubmission review experience are valuable in assisting and evaluating portions of the bidding submission, such as verifying the comprehensiveness of the information. The technical director on the other hand would focus on the critical elements that affect the architectural aesthetic appearance and performance, by evaluating the details among the submittals. Once the evaluation is completed, it would be sent over to the translator for the Chinese translation, and the bilingual junior team members would review the final version of the translation before sending out the package to the project owner (Figure 10).

As the workflow has been established, individual workloads are dramatically reduced, while still keeping the evaluations relevant. The lean concept once again has been reflected in the refinement process:

- Identify and eliminate nonvalue-adding activities in the design (principle #1) – the team leader spread out the task to his team in order to reduce his or her own workload.

- The output value and quality was maintained regardless of the increased number of bidder submissions through systematic considerations of the project owner's requirements (principle #2).

The project owner's preference, however, may not necessarily be the candidates that the consultant recommended. To ensure the design team is able to work with the best

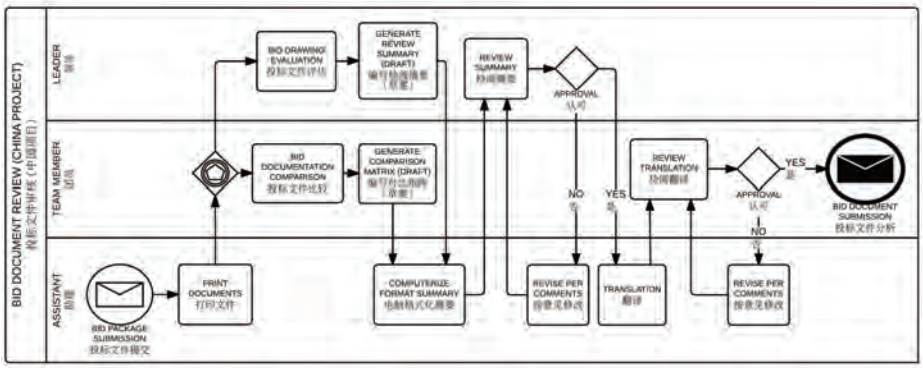

Figure 10. Bid document review workflow (China projects) (Source: Allan Chung)
图10. 投标文件审核工作流程（中国项目）（来源：艾伦钟）

依据研究者在设计阶段中，如图表1中所识别，所观察到的每一项设计活动的约束与宗旨，图表2显示了外墙设计与制作过程和精益原则的关联。以下的分析进一步揭示有关过程是如何与精益原则相关的（图9）。

设计文件的完成离不开双语团员的协助，翻译阐明图纸与规格给当地投标商。当过程进一步进化，常见设计与材料术语被标准化及统一化，并将英文注释与中文翻译连在一起。这容许其他团员存取及使用标准术语到他们的图纸上。通过减少易变及文件翻译的过渡时间，这持续的流程改进（原则＃7）有助图纸生成的效率。

在传统施工图审核过程中双语团员协助进一步改进翻译语言，以避免审核意见在翻译中丧失原意，导致意见错误传达及低效率的文件重交。通过对审核意见有更深的理解，或与技术总监进一步沟通来充分理解审核意见或问题。

为与精益概念一致，以上过程被进一步调整：

- 识别并消除在设计内的无价值附加活动（原则＃1）– 通过在第一次提交文件中提供更深入的审核意见，顾问总监可以分散他的工作量，让他的学员和助理依据他先前的审核意见，加上恰当的辅导和沟通，对重新提交的文件进行跟进，替代顾问总监亲自跟进有关文件，以尽量减少自己在无价值附加活动的时间。（重新提交文件的审查工作）。

- 以标准化来减少设计文件审批周期时间（原则＃4）– 当团员了解“诀窍“和最终输出的寄望，他们本来的间隔时间相应减少。

- 标准化成为设计过程中持续改进的基础（原则＃7）– 对程序进一步减少间隔时间和周期时间，一份标准审核意见逐渐型成并与中文翻译在电子表格中连在一起，这样总监只需选择适用的审核意见，而报告侧可由助理以更快的方法来形式化。

随着在投标审核过程中投标商的增加与时间的约束，人手支援是必要的。资历较浅的团员具有丰富的施工图重交审核经验对协助与评审投标提案的某些特定部分有一定的价值。它们可以帮助验证资料的全面性。在另一方面，技术总监将侧重于影响了建筑美学的外观和性能，评估提交文件的节点设计。当评估完成后，将它发送给翻译员翻译为中文，然后在评审报告发给前业主由双语团员检审查最终翻译版本（图10）。

当工作流程建立，每个人的工作量亦大大减轻的同时，评估亦能保持其中立性。精益概念在优化过程再次被体现：

subcontractor, an extra step is made by the consultant team by requesting observation tours of both factory and completed projects of the pending subcontractors before determining the awarded bidder (refer to the highlighted portion in Figure 04). Another layer of benchmarking was performed by reviewing the subcontractor's "back of house" and interviewing other building management groups (principle #6).

Although there are unforeseen issues still unexamined, such as maintenance and sufficient training of construction crews, this additional step helps the design team to adjust their time and resources in the following shop drawing review process by having a better idea of subcontractors' skill and experience through examining their documentation quality and their shop environment.

Unit of Analysis / Benchmarking

The shop drawing review process allows us to evaluate the efficiency of the lean concept implementation. The submittals transition log provides the following information:

- incoming submission date
- outgoing feedback date
- the duration days of the review process for each submission
- the submission content

The transition log of the following two projects have been reviewed and compared.

Project A
26-story, 915,000 sq.ft., symmetric twin tower, located in Guangzhou, China (Figure 11).

Completed in 2008, the drawings were reviewed from May 2006 to July 2007.

The unitized curtain wall system features stone, glass and metal, with the following six major systems in the project:

- Typical unitized system with stone, glass and metal
- Stick system along the base with stone glass and metal
- Roof screen wall with stone and louver
- Ballroom podium cladding with glass and metal

Figure 11. Grand Hyatt Hotel, Guangzhou, China (Source: Goettsch Partners)
图11：君悦大酒店，广州，中国（来源：美国gp建筑事务所）

- 识别并消除在设计内的无价值附加活动（原则＃1）– 领队分开任务交给了他的团队，以减轻自己的工作量。
- 通过有系统的考虑项目业主要求，不管投标商提案数量增加，输出值和质量均维持其水准（原则＃2）。

项目业主的偏爱未必是顾问建议的候选人。为了保证设计团队能够与最好的分包商合作，顾问另追加一个步骤，在确定中标分包商前先要求巡视观察候选分包商的工厂与其完成的项目（详见 图04 强调部分）。通过审核分包商的“后勤”及与其他大厦管理小组会面来设立另一层基准（原则＃6）。

尽管还有一些不可预见的问题未被审视，如施工团队在数量的维持及和培训的足量，但通过检查分包商的文件质量和他们工厂环境以对其能力和经验更深入的理解，这额外的步骤能帮助设计团队对接下来的施工图审核过程作出恰当的时间与资源调整。

分析单位/基准

的施工图审核过程让我们能够进一步评估精益概念的执行效率。文件提交记录中提供以下信息：

- 文件提交日期
- 文件反馈日期
- 每个提交文件审查过程的历时
- 提交文件的内容

以下两个项目文件提交记录进行了回顾和比较。

项目A
26层，915000平方尺，对称双塔，位于中国广州（图11）。

2008年完成，施工图审核过程从2006年5月至2007年7月。

单元式幕墙系统包含石材，玻璃和金属，并分为以下六大系统：

- 典型单元式系统带石材，玻璃和金属
- 沿底部的框架式系统带石材，玻璃和金属
- 屋面屏围墙带石材和百叶
- 宴会厅裙楼包覆带玻璃和金属
- 连桥包覆带玻璃与金属
- 在酒店入口的结构玻璃墙系统

- Sky bridge cladding with glass and metal
- Structural glass wall system at the hotel entrance

Project B

21-story, 441,300 sq.ft., single tower, located in Suzhou, China (Figure 12).

Completed in 2013, the drawings were reviewed from August 2010 to November 2011.

The unitized curtain wall system features stone, glass and metal, with the following nine major systems in the project:

- Typical unitized system one with shingle glass wall with integrated shading device track
- Typical unitized system two with glass and projected stone fins
- Typical unitized system three with glass and metal at double height recessed corners

Figure 12. Soochow Securities Headquarters, Suzhou, China (Source: Goettsch Partners)
图12. 东吴证券总部，苏州，中国（来源：美国gp建筑事务所）

项目B

21层，441300平方尺，单塔，位于中国苏州（图12）。

2013年完成，施工图审核过程从2010年8月至2011年11月。

单元式幕墙系统包含石材，玻璃和金属，并分为以下九大系统：

- 典型单元式系统一带瓦片式玻璃幕墙及整合遮阳设备轨道
- 典型单元式系统二带玻璃和突出石材翼
- 典型单元式系统三带玻璃和金属在双层高度的内退角落
- 沿底部的框架式系统带玻璃，金属和突出石材翼
- 屋面屏围墙带玻璃，百叶和突出石材翼
- 角落悬挑墙带玻璃和突出石材翼
- 裙楼包覆带玻璃和金属
- 在大堂入口的结构玻璃墙系统
- 在塔顶的三角玻璃天窗系统

两者之间的比较相等。 例如，

- 这两个项目均是100m内高，
- 两者均位于中国的东南部地区，两者的结构设计标准，如风力，地震和地形粗糙度，与及场地附近的遮断物都比较相似。
- 这两个项目的外墙工程设计、 制造和安装均为相同的幕墙分包商。

虽然项目A的大小比项目B大两倍，但它是一个对称的双塔建筑物，其外墙设计和节点都是相同的。

尽管两者图纸审核历时相似，A和B的文件提交送审数量是49对33，这意味着设计团队在项目B中的提案审查比项目A

少32%，具有更小的压力与紧张的步伐。项目A的文件反馈比其接收的送审文件少35%是因为重新提交的图纸和回复未完全解决先前的审核意见而没有审核。值得提及，项目B外墙系统的设计、组件与拼接相比项目A更为复杂。

通过比较，可作出以下推论：

- 历时 – 尽管项目B中的幕墙系统比项目A更为复杂，但团队能够在管理及完成审核过程上与上一个项目的审核过程历时相一致。

- Stick system along the base with glass, metal and projected stone fins
- Roof screen wall with glass, louver and projected stone fins
- Corner cantilevered wall with glass and projected stone fins
- Podium cladding with glass and metal
- Structural glass wall system at the lobby entrance
- Skylight system with triangulated glass at top of tower

The comparisons between the two are fairly even. For instance:

- Both projects are within 100m tall,
- Both are located in the southeast region of China, so that the structural design criteria, such as wind, seismic and the terrain roughness and obstructions around the site, are relatively similar.
- The engineering, fabrication and installation of the enclosure for both projects were done by the same façade subcontractor.

Although Project A is double in size compares to Project B, it is a symmetric twin tower building, so that the façade design and detail are identical.

While the drawing review duration of the two are similar, the number of incoming submittals between A and B is 49 vs. 33, which mean the design team had 32% less submittals to review in B compare to A, with a less stressful and intensive pace. The outgoing correspondence in A is 35% less than its incoming submittals because the resubmission had not been reviewed as their drawings, and responses did not fully address previous review comments. It is worth mentioning, that the façade design in Project B is more complicated in term of system designs, components and interfaces compared to Project A.

Through the comparison, the following deductions can be made:

- Duration – while the complexity of the façade systems in Project B is more advanced than Project A, the team was able to manage and complete the review process to match the previous project review duration.
- Number of outgoing correspondence – the review comments from the design team are clearer for the façade subcontractor to understand. On the subcontractor side, with their additional four years of experience working with other foreign design teams, not only were their drawings more well-defined, their resubmissions accurately addressed the review comments. The coordination cooperation process between the two parties was shortened.
- Efficiency rate – this is the number of resubmissions divided by the duration of the overall review process. The efficiency rate was 49/14 = 3.5 in Project A, and 33/14 = 2.4 in Project B. The lower efficiency rate means less time of involvement to review the drawings within the timeframe. This leads to the design team requiring less man-hours to engage the coordination process, while still able to maintain a high level quantity control on subcontractor's submissions with effective communication and understanding.

Conclusion

The conventional QAQC system is an excellent measure to set a benchmark in the pre-construction stage. However, due to the nature of the project location, along with the language and culture differentiation, and lack of understanding to the local workmanship, long distance overseeing becomes extremely challenging. The well-established QAQC system will need to accommodate those new situations, which involve conversion of input to output, flow of information and value generation. The implementation of the lean concept in façade design and pre-construction phases is prominent when the QAQC system is being practiced in overseas projects.

Through experience built by exploring local façade subcontractors' shop and field operations to understand their skill and workmanship for varies of projects in China, the design and consultant team are able to enhance the architectural product quality through long distance operations and oversight. There are cases where the results are not satisfied as expected; those experiences are part of the learning curve to create a better result for the next projects to continuously improve the design process (principle #7). From the case study, we can see that recent completed projects with more complicated façade systems required less

- 外发反馈数量 – 设计团队审核意见对外墙分包商更为清晰。在分包商方面，他们与其他外国设计团队在这四年间的工作的经验不仅使他们的图纸更明确，与及他们准确地解决设计团队提出的审核意见。这使双方协调合作进程缩短。
- 有效率 – 这是重新提交量除以整体的审查过程的历时。项目 A 效率为 49/14 = 3.5，项目 B 效率为 33/14 = 2.4。效率值低意味着在整体图纸审核时间内的参与较少。这也使是设计团队需要较少的工时去参与协调进程，同时仍能对分包商的提案保持高水准的质量控制及高效率的沟通和理解。

结论

常规质检系统是一个在施工前阶段设立基准的良好措施。然而，由于项目位置的性质，语言与文化差异，与及对当地手艺缺乏了解，长距离监督变得极具挑战性。完善的质检系统需要重新适应这些新的情况，这涉及投入转换为输出，信息流动及价值创造。当在海外项目外墙设计和施工前阶段实施质检系统时，精益理念的履行更为突出。

通过对国内不同项目的深入探索当地外墙分包商的工厂和现场操作，从而了解他们的技术和工艺以建立相关经验，设计与咨询团队能够在远距离操作和监督中加强建筑产品的质量。有些情况下，结果并不如预期理想，但这些经验也成为学习曲线一部分并为下一个项目营造更好的结果并不断地改进设计过程（原则＃7）。

从案例研究中，相比早期较间单的外墙系统项目，我们可以看到最近完成的项目带有更复杂的外墙系统在审查过程中需要更少的工时来完成。这是一个在设计团队中将精益的理念融入到设计过程中的正面结果。

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man-hours in the review process compared to projects with simpler façade system that were completed in previous years. This is a positive result of implementing the lean concept into the design process.

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