

# COMPUTATIONAL CONSTRUCTS

ARCHITECTURAL DESIGN,  
LOGIC AND THEORY

Hon. Editor Daxia Li

Editors Shouheng Chen Shuyi Li Josh Lobel

美国麻省理工学院建筑系 论文集  
MIT COMPUTATION GROUP

## 数字营造

建筑设计·运算逻辑·认知理论

名誉主编 李大夏 主编 陈寿恒 李书谊 乔希·洛贝尔

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## 致谢

非常感谢共同参与和支持本书编写工作的所有朋友！这里我们要诚挚地感谢美国麻省理工学院建筑学院的教授们对本书的指导，尤其是数字化运算设计研究小组的长仓武彦教授和特里·莱特教授以及建筑系主任张永和教授。同时，我们对世界华人建筑师协会（WACA）的大力支持表示由衷的感谢，特别要感谢李大夏教授、邢同和教授和张健教授对本书提出的宝贵意见。另外，本书的顺利进行还离不开编委会所有成员以及中国建筑工业出版社编辑们的共同努力，这里要特别感谢徐冉编辑、李长君先生、俞辉先生和陈筱平女士对本书的支持。

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## 序一

数字化运算与设计之间“亲密接触”的历史是很短暂的，而它们在历史发展长河中“藕断丝连”的关系一直被掩盖了起来。在伊恩·萨瑟兰(Ian Sutherland)发明第一个数字草图绘制工具至今45年后，通过电脑渲染制作的设计表现图的仿真性已经达到了炉火纯青的地步。就像其他相关行业一样，一些曾在建筑实践中被公认的难题，包括从视觉表现到结构分析等层面的，都已经被逐步地解决。如今对当代建筑师来说真正的难题是建筑设计的本体论问题。本书收录的作品是对这些问题发起的强烈挑战。这里包括：对数字化运算设计所面对的设计问题含糊性的描述——数字化运算如何解决和应付设计问题自身的或者说是客观上不可避免的不准确性，数字化运算设计如何成为帮助那些对设计问题持不同见解的执业建筑师们协同合作的媒介，几何学与形体之间的关联性问题，数字化运算设计的语法和语义以及它们的设计意图与传统的空间使用概念和设计语言学的关系问题。这些问题尽管深深地浸渍在学术研究的理性框架中，但它们却也是当代建筑设计实践在技术应用的过程中每天都要面对和需要解决的核心问题。

从本书的手稿中，你能找到成功的，或者还在摸索阶段的，又或者是非常有野心而老练的技术流的执业设计师们对数字运算设计和技术创新的简短描述。这些描述以一种毫无修饰的形态表现出来，组成了一本由建筑实践者编写的论文集。他们提出了设计问题但并不是每个问题都能得到全面的解决。此外，它是一本关于美国麻省理工学院数字化运算研究小组近期毕业生的研究成果的著作。这些文章展示他们传承了本研究小组对技术勇于创新的精神和参与了以美国麻省理工学院为中心的研究网络和实践团队的建设。它们是本研究小组在教育实践领域的实力的体现。

美国麻省理工学院建筑系是最早把数字化运算纳入正规教育范畴的建筑学系之一。威廉·米切尔(William J. Mitchell)系主任早年创办了这个课程并坚持在这个研究学系授课至今。我们的教授团队由包括了形体语法的创立人乔治·史丹尼(George Stiny)在内的七位教授和多位声名卓越的资深研究科学家组成。他们多样化的研究课题拓宽了数字化运算和人造环境的领域，从衍生式设计和数字建造到嵌入式和移动式运算应用等等。

建筑设计和数字化运算设计之间总是处于一种紧张状态，有时会出现两者之间的相互“仇恨”，但同时它们之间的互动也会产生巨大的创新动力。美国麻省理工学院的设计与运算课程曾经受到一些设计行业的专家的巨大质疑。他们甚至认为我们这个课题是极具争议性的，并正处于一个早期发展的历史阶段。他们怀疑这个课题能否为建筑行业带来建设性的影响，还是作为一种负面的因素而将会从重要的人文主义课题中被剔除掉。然而，现在数字化运算在设计行业的地位已经得到明确的和广泛的认可。这样，给我们遗留下来的是关于数字化运算的基本原理和对其实践



效应的探讨问题，还有它们如何解决全球对空间和形体的应用问题、基础设施的建设和使用问题、人类的行为学和生态学之间的问题等等。

数字化运算设计一直保留着它的核心基础——严格的逻辑理论框架及其专一性和差异性。现代数字化运算的巨大发展潜力和所继承的建立在此框架上的多重目的性，结合一些被大家广为认可的实践项目（这些项目的内部结构被更加容易接近和有亲和力的外层界面所掩盖），模糊化了它的逻辑框架，但是我们仍然能够从它的成果中识别出它的核心基础框架来。运算的过程是一种熟练地掌握并解决所设定的设计问题的过程，但是在这个过程中我们仍然需要对设计任务有明示性的定义。家庭电脑在读者阅读这本书的时候可能已经解决了读者一生中能解决的所有数学运算问题，然而就像是电影《终结者》(Terminator)的“天眼”和其他宣扬世界末日的科幻小说那样，我们对蕴含了世界上数字化运算总能量的集合体仍然没有一个独特的设计（编者注：作者运用一部著名的电影的情节来讲述数字化设计的潜能还远没有被开发）。数字化运算的命运在这个时代的历史地位就像是道格拉斯·埃文的《沉思》(Deep Thought)，它能够解决“终极问题”(Ultimate Question)，但是它最终也不能给问题本身提出清晰的定义（编者注：作者运用一部著名的电影的情节来讲述数字化设计的过程是解决设计问题的过程而不是寻找和定义问题本身的过程）。

这种对数字化运算的认知和典型的设计思维存在着明显的反差，而且这种反差或者更甚于它与其他行业之间的反差。设计不是关于问题的横断面和如何界定解决问题的方法，而是一种发掘和探索的过程，是理解设计问题和界定解决问题方法的联动式的处理的方法。设计的终极目标是要达到把完全不同的、完全没有联系的设计意图结合在一起，并把这些因素综合起来成为一个整体。设计是在研究的过程中发展和寻找合理的建筑空间和解决功能使用问题的方法。即便它与设计存在明显的反差，数字化运算能使设计在很多层面上变得更加的强大。它在设计的特定阶段，或者是对某个特定的领域，或者是结构分析，或者是视觉表现等等提供快速的回馈意见。如果我们能够明确地把完全不同的设计意图表达出来，我们就能通过寻找最完善的结构和能源使用组合来优化各方的利益。举例说，以寻找多变的几何形体为目的重复性繁衍手段被应用到衍生式的技术上(Generative Techniques)，甚至被应用到解决工业的可建性和细部构建的问题上。几何形体在不同的设计媒体间的转换和把语义上的设计意图转化成设计成果的技术，包括从三维到二维，从数据列表到空间示例，甚至实现对颇有分歧的媒介像几何形体和自然体形之间的转换，已经成为学生和执业建筑师的日常设计工具的一部分。再者，通过数字化运算术语来诠释设计方法和通过数字化繁衍技术来描述设计问题让我们能够理解所设定的设计问题和寻找解决这些问题的方法。

有很多设计创新只能通过设计实践才能有所成就。由实际的建造项目所提供的资源比在学术研究层面上所能提供得更多。同样的，设计实践和建造所要面对的限

制条件和挑战很难在学术环境里被复制。由这些设计限制条件所引起的复杂的设计问题反而能够促使设计创新的出现。然而，美国麻省理工学院就像是思想创新的熔炉，很多新的发明每天都在各个实验室里锤炼，或者从和其他院校和公司的合作中被发掘出来。由于这个原因，我们的毕业生会不断地回到美国麻省理工学院并和我们的在校学生、其他毕业生、教授和美国麻省理工学院这个学校保持紧密合作关系。未来就在前方，我们作为数字化运算设计研究小组的成员希望陪伴美国麻省理工学院一起看到这个未来的到来。

丹尼斯·谢尔登  
美国麻省理工学院数字化运算设计研究小组建筑实践副教授  
盖里技术首席执行官



## Foreword I

In the short history of computation's complex relationship to design, a long distance has been covered. Now forty five years since Ivan Sutherland first produced the first digital architectural sketches, computational rendering produces images of design that are indistinguishable from their potential visual appearance. As with many other disciplines, many of what were once thought to be the hard problems of architectural practice – from visualization to structural analysis – have been solved. What remain before us are the truly difficult ontological problems of design. The work in this publication presents forays into these challenging problems. These include questions of computation on ambiguity – how computing addresses or falls down and resurrects itself against problems whose definition is intentionally or necessarily imprecise. Questions of computation as a medium of collaboration between practitioners who see and interact with the encodings of design through the lenses of disparate disciplines. Questions of geometry versus form. Questions of the relationship between syntax, semantics and intentions as applied to spatial and traditional linguistic media. These questions, while deeply steeped in the intellectual framework of academic work, are the heart of problems that are expressed in the every day struggles of professional practice in coming to terms with the technology that surrounds them and infuses their work.

In the pages of this folio you will find a snapshot of the successes, struggles and ambitions of technologically adept practitioners, researchers, and educators. This snapshot is presented in raw form, as a compilation of research in practice by the professionals who have created demanding problems whose solutions are as yet only partly determined. It is moreover the work of recent graduates who have maintained their roots to the computational ambitions of the program, and participate in an expanded network of research and practice whose epicenter remains at MIT. It speaks to the strength of the extended community of the program both in academia and beyond to its ties to professional practice.

MIT's Department of Architecture was one of the first programs to define computation as a field of study on par with other tracks in the discipline. Dean William J. Mitchell initiated the PhD program in design and computation when he joined MIT and remains one of the Computation Group faculties. The faculty includes George Stiny, the founding father of shape grammars, with six faculty in total as well as distinguished senior research scientists, whose interests together span the spectrum of computation and the built environment, from generative design and digital fabrication to embedded and mobile computing applications.

There has always been a tension between Architectural Design and Computation that has at times engendered strong animosity but also generated tremendous creativity. The Design and Computation program harkens from a time



when computing was viewed with tremendous suspicion by established leaders of the field, and we are not far in history from early debates on the topic that openly questioned whether computation had any constructive role in the field or would serve as a dark force that would inevitably draw the discipline away from its important humanist agenda. The question of whether computation has a role in the discipline has now been unequivocally answered, but important questions remain about the fundamental approaches and efficacies of each, and how they interface when applied to worldly questions of space and form, infrastructure and occupancy, human behavior and ecology.

Digital computation remains at its core firmly founded on a fabric of logic, specificity and difference. The vast capacity of modern computation and successive layers of intention built on top of these foundations, coupled with substantial work to hide internal structures behind more accessible, human friendly interfaces have obscured these computational structures, but the fundamental fabric of computation is still apparent in the effects it produces. Computing is unfathomably adept at solving well formulated problems, but still requires explicit and unambiguous definition of the tasks it is directed toward. The computer on your desk will solve many more arithmetic problems in the time you will read this article than you will in your lifetime, but in contrast with the apocalyptic lore of Terminator and other doomsday science fiction, the aggregate body of the world's computational power has yet to devise a unique problem of its own design. The fate of computing at this point in its history is closer to Douglas Evans' Deep Thought, able to solve the Ultimate Question, but ultimately unable to determine what the question is.

This computational approach to knowing stands in stark contrast to design thinking in particular, and more so than other fields of inquiry. Design is not a question of problem traversal and solution identification, but a journey of exploration and discovery, of problem resolution through elaboration of the question in parallel with determining an answer. Design at its best is achieved by bringing together disparate, previously unconnected intentions and synthesizing a new issue of concern in their union. Design is problem solving occurring in a search space that ebbs and flows over the course of the inquiry. Computation is immensely powerful to design in many ways. It provides rapid feedback on point snapshots of the state of design and in specific domains of interest, a structural analysis here, a visualization there. We can optimize across combinations of interest finding the best combination of structure and energy performance, if we can explicitly state the aggregate best of such disparate intentions. The drudgery of repetitive propagation of intentions across varying geometries is increasingly used in generative techniques, even on industrial grade problems of constructability and detailing. And the translation of geometric and semantic intentions between design media, from 3D to 2D, from tabular data to spatial instantiation, and even from such divergent media as geometry and physical form, has become part of the students and practitioners every day tool box. Moreover, formally interpreting a design approach in the language of computation,

and allowing its digital propagation to return corollary implications of our problem description, provides a litmus test of our ability to understand the problems we pose and the fidelity of our ability to pose them.

There are many design innovations that can only be accomplished in professional practice. The resources available on real construction projects greatly exceed those available to academia. Similarly, the constraints and challenges of professional design and construction projects are difficult to duplicate in the academic environment, constraints that generate the tough problems from which innovations in the field emerge. At the same time, there is a reason that many of the program's graduates continue to return to MIT and continue to maintain ties to other students and alumni, to faculty, and to the Institute. MIT is a crucible for ideas and great innovations are being cooked up every day in its labs, or arrive from collaborating institutions and companies. The future will arrive early here, and we, the extended members of this community, will want to be here when it appears.

Dennis R. Shelden

Associate Professor in the Practice of Architecture, Computation Group, MIT  
Chief Technology Officer, Gehry Technologies



## 序二

翻开本书就会有一种不寻常的感觉，一种好奇的吸引力。

本书引领人们进入了一个广阔的数字化视野下的新建筑天地，也会不约而同让人们引起对数字化技术的兴趣。正如密斯·凡·德·罗揭示过的“技术不是一种方法，它本身就是一个世界”。

信息化、数字化时代使人们对建筑及其创造的空间不仅仅是感性的认识和传统的审美价值取向，而已经变得理性、科学性下的新思维方法和人类行为模式，由此而带来对建筑教学和建筑设计的一场革命，提供了崭新的理论诠释和更高的技术平台。

数字化的飞速发展是全球性新历史条件下的产物，它绝对不是简单的建筑绘图与运算工具的替代，而应该是空间认知、文化价值、广义建筑学被赋予新的内涵和实现保证，给建筑领域的创造灌注新的生命活力。

随着世界对生态环境、智能建筑的关注，更孕育、促进了数字化、媒体化的无限空间，数字化从现实空间向虚拟空间探索，从建筑的模糊性、静态性转向可以超越视觉的想象性、动态性，把不可思议变成事实可能。

本书中的“空间的重演者——在建筑空间中行走的虚拟人”，论述数字化下的四维表达能力，可以在动画格式中捕捉人在建筑空间中的各种身体反应，而且有趣地提出“隐私映射”的虚拟空间。另一篇“具备摄影功能的人”也与此文相辅相佐。在“媒体化空间设计中的认知学应用”论文中，通过引用数字媒体来改善空间质量的设计方法，使建筑设计超越了简单功能性的各种公共空间，表达完全的自由空间，正如文章中比喻的建筑“木偶”，通过建筑师牵拉使它变活起来，原本的物质空间可以由数字化激发出现多变的虚拟空间。

在建筑设计教学与实践中引入脚本语言，并把它制定为一种设计认知来挑战建筑表现，无疑也是本书中的又一吸引部分。从暗示规则到明示规则的建筑设计语法以及一体化设计的基本动因与三种设计模式都让人们，尤其是建筑师、建筑专业的学生，来了解数字化视野下的新概念、新技术，连同潜在的发展趋向。其中“数字化工具发展与建筑进步互动作用”与“性能驱动之建筑设计”论文都深入浅出，有实践参考意义，可以让人们在逻辑思维中、建筑师空间想象中感受到数字化下的新认知与可操作性的辅证满足。西班牙“高迪圣家族教堂参数化模型”与中国“营造法式”的运算解剖则让建筑师在追溯和回忆中找到回归，获得科学理性上的答案。

总而言之，信息化、数字化给建筑带来全新的进步。这本论文集给我留下不可忘记的印象，甚至促使我还想去寻找这方面的资料，吸收数字化知识的滋养。

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## 前言

大概八个月以前，我们成功地主办了第一届麻省理工学院数字化设计小组毕业生峰会，特邀的演讲嘉宾都是从我们研究小组毕业的博士或者硕士。他们从世界各地回到母校，有的已经毕业了10年以上。在此峰会上，他们向我们展示了正在进行的研究项目、设计方案和教学成果。大会涉及的主题非常广泛，其中介绍了他们发明的、通过编写电脑程序的手段来实现的新的设计工具，讲解了应用到设计和建造行业的新建造技术，分享了他们发展的应用在教学中的新数字化设计方法和理论，甚至有人在尝试搭建一个理解设计技术进步的平台。对于我们教育团队来说，这也是首次有机会更全面地了解我们的毕业生对于数字化设计这个课题的诠释。

会后不久，我们的特邀演讲嘉宾陈寿恒（Shouheng Chen）和峰会的组织者乔希·洛贝尔（Josh Lobel）希望把这次峰会激烈讨论的成果和精神通过合适的方式传播出去。恰逢此时，我们收到由世界华人建筑师协会数码建筑学术委员会发来的邀请，邀请我们共同出版关于数字化设计的专题书籍，这也是本书的由来。收录在本书的多个研究成果都出自此峰会的演讲稿，同时也汇集了一些由于某些原因而无法出席的毕业生的作品。它们充分地展现了我们数字化设计研究小组的成果，让读者能全面地理解数字化设计的内涵以及我们研究小组在此作出的不懈努力。

代表麻省理工学院数字化研究小组的成员，我们恭喜陈寿恒、乔希·洛贝尔和本文集所有的作者。我们希望本书对推动数字化建筑在实践和学术层面上的进步起到积极的作用，同时也希望数字化设计能引起更多读者的关注并促使更多同类书籍的出版。

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## Preface

It was only eight months ago when two bright and ambitious graduates of the Computation group of MIT's Department of Architecture came up with the idea of this book following the successful organization and realization of the first annual MIT Computation Group Alumni Symposium. The invited speakers at the symposium were all former students who had achieved PhD or Masters of Science degrees in design and computation.

In that symposium, graduates from as far back as ten or so years ago returned to MIT to present and discuss their ongoing research, projects, and teaching. Some were attempting to develop software for new design tools. Some were using new digital technologies for building and construction. Some were seeking new computational methods and theories for teaching. Others were trying to establish critical frameworks to understand the impact of design technologies. For most of us there, it was the first time that we had a commanding view of the wide range of exciting, innovative ideas that have come from our students.

Immediately after the symposium, Shouheng Chen, an alumnus of the Computation Group and presenter approached Josh Lobel, the symposium's originator and organizer, with the idea to capture and convey both the spirit and the tangible outcomes of the symposium in a book to be published with the support of the World Association of Chinese Architects (WACA). This book came into being as a selection of work presented at the symposium, along with contributions from others who were not able to attend. For those really wondering what the Computation group at MIT is about, perhaps the best description can be found in pages of this book.

On behalf of all the members of the Computation Group, we congratulate Shouheng, Josh, and all the contributors of articles to this book. We hope that the book will be an inspiration to many others to come in the future.

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## 目录

5 致谢

7 序一

13 序二

15 前言

### 1

## 第一部分 实践

### 2 性能驱动之建筑设计

作者: Stylianos Dritsas

翻译: 李长君

### 16 数字工具的发展与建筑设计进步的互动作用

作者: Shouheng Chen

翻译: 李书谊

### 41 具备摄影功能的人: 对应用于描述建筑环境的综合性电影摄影术的研究

作者: Panagiotis Chatzitsakyris, Takehiko Nagakura

翻译: 王骁勇

### 54 一体化设计

作者: Eleftheria E. Fasoulaki

翻译: 钱烨

### 71 空间的重演者——在建筑空间中行走的虚拟人

作者: Taro Narahara

翻译: 邓昕 许亦君

### 84 数字控制建造系统 (DFPS): 定制需求

作者: Dimitris Papanikolaou

翻译: 李书谊

### 103

## 第二部分 理论

### 104 计算机辅助设计

作者: Josh Lobel

翻译: 张燕

113 营造法式的运算解析

作者: Andrew I-kang Li

翻译: 袁博

126 运算图像和运算成像技术: 关于设计与运算的一段简史

作者: Alise Upitis

翻译: 钱烨

137 建筑设计语法: 从暗示规则到明示规则

作者: Magdalini-Eleni Pantazi

翻译: 李书谊

151

第三部分 教育

152 设计分析和参数化设计: 介绍高迪的圣家族教堂的参数化模型

作者: Carlos Roberto Barrios

翻译: 袁博

162 CAD图纸和模型制作一体化: 电脑控制式模型工作室

作者: Gabriela Celani

翻译: 李书谊

180 在建筑设计课中引入脚本语言

作者: Daniel Cardoso

翻译: 邓昕 许亦君

191 媒体化空间设计中的认知学应用

作者: Marianthi Liapi

翻译: 王骁勇

202 后记

207 作者简介

215 译者简介

219 专有术语



# Content

- 5 Acknowledgement
- 10 Foreword I
- 13 Foreword II
- 16 Preface

## 1

### Practice

- 2 Performance-Driven Architectural Design  
Stylianios Dritsas

- 16 Correlation Between Digital Tooling and the Advancement in Architecture  
Shouheng Chen

- 41 Man with the Movie Camera: An Approach to Synthetic Cinematography for Built Environments  
Panagiotis Chatzitsakyris, Takehiko Nagakura

- 54 Integrated Design  
Eleftheria E. Fasoulaki

- 71 The Space Re-Actor  
Walking a Synthetic Man through Architectural Space  
Taro Narahara

- 84 Digital Fabrication Production System (DFPS) : Customization on Demand  
Dimitris Papanikolaou