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运算化设计：知识时代的新设计

Computational Design: Design in the Age of a Knowledge Society

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摘要：运算化时代的理论有必要通过运算化形式表达。今天大多数的数学问题是基于机器的处理。然而对于设计，我们更倾向于把电脑当作一种工具，而不是一个形成概念的媒介。关于设计的运算化理论，有必要是关于人类行动的理论。行动改变现状。设计是我们各种活动中固有的一个部分。关于设计的运算化概念有必要不成为过去某种理论的延续；它对立于那些受制于已有工具的思想。驾驭运算化设计的是意识到未来变数的希冀。设计不再被动地响应期待，而是以更积极的热情面对变化。信息处理已经构成了一种新的生态。设计正在变成一种变化的力量。

关键词：设计学；运算化设计；原型；设计研究

Abstract: Theory in the age of computation is by necessity expressed in computational form. Most of today's mathematics is based on machine processing. However, when it comes to design, it is easier to understand the computer as a tool than as a conceptual medium. A computational theory of design is by necessity a theory of human action. We are what we do. And design is an intrinsic part of our activities. A computational theory of design is also by necessity not in continuation of past theories; it is rather in opposition to an understanding that was dependent upon the tools of the past. What drives computational design is an awareness of anticipation. In other words, design is no longer in reaction to expectations, but a pro-active endeavor. It is irrelevant which computers are used. Relevant is the fact that information processing constitutes a new ecology. Within this understanding, design is becoming a force of change.

Key words: Design; Computational Design; Prototype; Design Research

当今世界，知识正在变得越来越运算化。以前与知识的获取、交流及批评的方式与方法都渐渐淡出，取而代之的是由数字化手段实现的信息探寻、知识分配与价值评估。帕斯卡（Pascal）、莱布尼兹（Leibniz）和皮尔斯（Peirce）为此变化，搭建了多项必要的概念结构。在学习知识的动机、获取知识的渠道及分享知识的意愿等问题上，他们提出许多相关的问题；换句话来讲，他们给出了认知方面的定义。更近的，布尔（Boole）①、维纳（Wiener）[1]和凡·诺依曼（von Neumann）提供了所需的科学基础，并最终由阿塔那索夫（Atanasoff）、祖萨（Zuse）、埃克特（Eckert）与莫奇莱（Mauchly）制造出机器③。电脑图像、可视化、桌面出版、CAD、多媒体、虚拟现实、互联网、万维网，已经成为了我们生活的一部分，还有更多的知识也将来到我们身边。在这一进程中，科学也开始变得趋向运算化：最耳熟能详的便是物理、生物、化学的转变；工程领域，在材料应用、机器人技术，甚至是计算机生产及软件自动生成的各个方面，都经历着同样的变化。在这样的大环境下，设计领域发生了怎样变化？

1 现状

目前的普遍现象是——计算机和设计师仅仅是工具与使用者的关系。事实上，在设计领域内部，一直存在计算机是否能够替代设计师的争论，至少计算机已经取代了铅笔和马克笔，以及枯燥的模型制作。平面设计师又一次走在最前端，他们乐于、也最容易开拓各种新的领域，比如字体设计、按需出版和电子出版。他们很快就发现数字技术并不仅仅代表着原有功能上的先进工具，更代表着活动领域的拓宽。激光显示器、扫描仪、手绘板，硬盘，不断尝试整合越来越多的网络工具（浏览器，Applets程序，Frames语言）。科学抽样、拼接、变异、超链接等手段方法也加入进来，正是这样，多媒体和网络交互为印刷品增色不少。我认为最成功的范例是传媒设计的新应用：虚拟设计室，也就是设计师基于已有的技术与工作方式，设计出一种新的互动工作环境。因此运算化成为设计工作的组织机制，并在实践中根据对它的评估，不断接受新的测试。但是，即使在平面设计领域，根本问题还是被回避了：我们是否认定人类大众是一个不会随着科学和技术改变的群体？我们是否在“设计”我们自己的公众，为植根社会且更具个性化的人们之间的互动，发明各种形式和手段？我们如何超越对于大众传播的迷恋，令小众传播为目标的“设计”，在内容与表现手段上都能够与大众传播取得平衡？我们又该如何改变固有的想法，尝试革新性交流的手段与动机？

技术，尽管已经被创新地应用在传媒设计领域，但仍然远远超出我们已经应用的范畴。在其它设计领域，主要是产品设计和工业设计，目前的情况还不是特别明朗。传统的工业设计几乎不能提供新的就业机会，需要数字整合的教育项目的进程也比较缓慢。可悲的是，教育工作者们已经习惯了不懈地思考工业革命模型的硬性条件，这些条件并不是依靠和设计相关的新思路，更多是基于对制造手段的预期要求。众所周之，在技术上的投资，诸如软硬件、维护、培训、研究等，费用高得令人咋舌。很少有人敢于尝试创业的风险，更不用提获得成功的人了。大企业为了巩固自己的强势地位，逐渐吸纳这样一些人，他们能够管理当前基于计算机或计算机辅助设计的复杂工作环境。在很多情况下，为了保护独立的知识产权，企业的设计并不公开。那些利用计算机及软件来开发先进产品的设计团队，甚至不配置上网设备。而当涉及到数字技术的时候，他们又不得不尝试不同的协作设计方法，这些注定都是要避开公众的视线隐蔽地进行。他们忽视了这种孤立的手段方法与其工作本身结构之间的矛盾性。结果是他们可以严守设计秘密（如新车模型、新玩具、新家具等等），但每次发布时却经常发现自己已经落后于市场了。

技术领先于设计并不仅仅表现在工业设计领域。在纺织业、时尚界、玩具商及室内设计中也非常明显，各种形式的设计还都是手工模式为主。难以避免的后果是各种设计缺陷都被计算机辅助设计掩盖了，结果扔给折扣市场顾客的都是些没有品味的产品。军事和人工智能领域之外，无论设计初衷是多么“高档”的、价格多么合适的小玩具，都不能在我们的文化中得体地存在。

2 设计理论的可能性

运算化设计认同工具与使用者之间的有机联系。运算化设计的目的在于通过这种联系转换出更多的可能性，并通过设计付诸实现。要达成这一目标，“运算”既不能像今天这样仅仅作为一个表达的媒介，也不能仅是产生变体，不管这种变体成不成系统，因为运算化已经成为设计本身的构成机制。设计理论是否真的可行的老问题，再次摆在我们的面前，如果可行，会以什么样的形式实现？

之前当这个问题还处在构想阶段的时候，理论只能是遵从实际的设计。最好的设计师，或者至少是那些将自己的想法透过文字表达出来的人，能够将自己的成就合理化。也就是说，他们仅仅是在设计被认同或者被公众认可之后再对自己的工作进行评价，这样的情况大家都早已司空见惯了。众所周之，设计从手工制作开始，在进化的过程中，设计在各类人类的尝试中第一次获得了公正的称号。但是随着手段与方法的拓展，设计又创造出自己的依据和概念的范畴。随着设计评论与设计历史的出现，设计理论与设计教育也一同建立起来。最初的理论必然是分析性的，通过观察和归纳获取新知识，这与设计普遍化进程中派生出的演绎和推导相互补充，结果是设计理论家能够尝试综合各类理论。俄罗斯构成主义、包豪斯、美国二战后的设计都是新概念领域的典型例子。其中有些取自形态学、结构主义、符号学，有些甚至源于心理学、语言学、社会学和工程学，还有一些由功能设计派生出来。近些年，系统运算式、启发式程序甚至遗传学都能在设计理论中有所体现。另外，“设计假设”同样利用运算化进行建模和检测。我自己的设计机器系统（Design Machine™）工作室也是这个方面的例子之一。

推论式的理论保持了结论性等式的魅力：即首先会有个设计的原因——设计项目，然后是设计的结果——设计衍变成可识别的物体，其特性通过商务交易和文化认同体现出来。其结果是，设计必须遵循阐述“如何设计”，以及“什么才是一个好设计”的理念。它的前景似乎越来越迷茫。首先，语言作为我们相互理解的最佳媒介，却不是保证人类活动的唯一必然因素，因为人类的本性并不单纯是语言的归纳与总结；其次，往往人们都认为好的设计之所以好，是由所处文脉决定的（比如形式上的、功能上的、结构上的等等）。显然，好的设计理论应该可以解释为什么有些设计就是不好的。由于这些问题都是借助语言的帮助而产生的，我们也认识到设计理论其实处在学科间，是跨学科的。我们可以对设计投以各种热情洋溢的褒义词藻，但是它们并不会对设计理论的实践及设计本身有太大帮助。尽管如此，我们并不否认设计对于语言的依赖。人类工程学、功能学、心理学、社会学与经济学各种概念，也开始影响与设计相关的问题和设计教育的课程设置。设计师经常向潜在客户陈述人类工程、文化或者符号学等方面的内容，而不是设计本身。之后，设计实践又开始在更倾向于保护书面内容的社会中，对建筑产品权益进行保护，而不再是含糊不清的视觉传达，因此，律师的语言也被借用到设计理论中来。

3 设计知识库

运算化设计已经告别了进退两难的境地，像其他运算化知识一样，融入到人类务实的生存状态中。我们都知道运算物理学（Computational Physics）既是理论，也是实践。作为理论，运算物理学从宇宙起源开始提出各种假设；作为实践，通过模拟各种假设来验证其真实性，并最终转化为各类探索宇宙的工具。模拟能够为我们研究宇宙提供各类新知识，同时也能帮助我们认识自身活动中的知识，这个过程中并不需要考虑我们是否是物理学家或者其它领域的专家（生物学、化学、哲学、艺术）。这些知识在实际工作中都能够为我们开拓思路提供前摄性（一种更主动面对未来变化的态度，往往通过自身主动的变化导致变化，而不是等待预料之外的变化而不知所措）的帮助，很容易让我们联想到在外太空开展的植物、动物，食物甚至是艺术的实验。运算工程学（Computational Engineering）让设计师整合了新材料与许多有趣的事物，为未来创造出更多的可能性：从分子或原子出发进行假设以构建新结构，并在其它自然资源加工处理之前，进行运算化测试。运算遗传学（Computational Genetics）这项实践活动的中心，就是为人类谋求更多的福祉。

运算化设计的主要意图是想借助超越主观的外力驱动设计，这些外力让设计在需求性评估、可能性评估、和体现人类特性的方式评估中变得可能且必要。这些评估都以数据的形式进行，更准确地讲是非常复杂的数据库。其他设计理论的本质是被动反应，

因此经常是投机性的；而运算化设计理论基于大量的数据，本质是前摄性的。运算化设计具有不可避免的局限性，一方面指在需要同时兼顾质量和数量的前提下，设计人员本身有限的搜集和组织数据的能力；另一方面指我们处理数据的高端运算化程序的能力非常有限。像其它运算化理论一样，运算化设计同时也是一种实践，是远远不同于我们日常活动形式在更广义的环境下进行的精确设计实验。他的成败取决于测试的结果，核心是关注人类最重要的资产——知识。运算化设计需要配备一个相应的知识库，这将超越目前所有设计博物馆、收藏馆及各类书籍、文章关于设计的一切内容。此外，这个知识库需要以今天人类全球化生存为依据，设置导航、搜索、检索的功能。我们需要从更广义的文化角度来审视人造物，连同它的规划及孕育它的设计。这个知识库还应该包含涉及视觉表达、运动、色彩、人体工程学，及其整合他信息传达手段（声音、材质、气味等）的运算化表达知识（Computational Expressed Knowledge）。实现这些目标任务艰巨，但又无法逃避。不幸的是，大多数被我们看做是“历史学校”的博物馆和收藏馆，就好比一个垃圾场，并没有收集设计真正所需的知识库。

设计知识库的典型例子之一，是已经在设计领域里广泛应用的计算机程序。事实上，一个CAD程序、字体设计程序、多媒体编辑程序，或者网络浏览器都是高度抽象的理论表达。在这些程序里，我们需要设定几何关系、材质特性、调节光线，完成动作、角度的设置，建立图片与声音文件的联系，整合文字内容和其它设计因素。当然这些工作只通过一个程序是完成不了的，但是至少可以建立起设计的一致性，或者令我们能够更好的理解设计。基于这些“理论”的设计实践，才是真正对设计任务的研究，并通过人造物（即设计的物质对象）数字化后的性能表现来评价设计。得益于成功的设计经验，一些较为成功的程序版本可以变得越来越好。在我写下这些话的时候，Netscape™ 3.0正式发布；这次它吸纳了远程电话会议技术，这点让我接下去的话变得不言自明了。在设计假设不断延续的进程中，有一些设计理论被证明做了不恰当的假设而逐渐消失。就在两年前，电话会议技术，这项传媒设计的主流创意，还拥有数十亿美元的潜在市场；但今天，它已经成为一项标准的浏览器功能。

我想对于视“使用程序”为设计活动说得更清楚一些：Macromedia Director™、Phontographer™、Alias™、Vellum™，或用于桌面出版的程序（Quarkexpress™、Pagemaker™），还有材质设计软件、珠宝设计软件等，这些都是我们能够在商店购买到的软件，然后应用在不同的工作中。但相对于铅笔、画笔、美工刀、木材或金属、胶水等，这些设计师原来的常用工具，程序就是他们曾经拥护和发明（比如电话会议）的理论精华。显然程序并都不能穷尽设计的各个环节，但却可以表述和整合与兴趣、多媒体、字体设计、CAD、出版物设计或在线广告相关的设计活动。编写程序的大多是由程序员、心理学家、设计师等组成的大型团队，他们需要综合各类物理学、数学、美学、符号学及人体工程学等知识。事实上，任何一个程序都是一次理论假设，再利用程序来检验假设。程序生成的最终产品能够与应用运算化工程创造出的新材料，或运算化遗传学研制出的新医药相媲美。

4 计算机并不仅仅是工具

事实上，新材料、新医药、新基因的创造都可以被理解成“设计”。我之所以用这个标题，意在表达在运算化时代下，设计变为一个涉猎范围更广的词。如果我们不能理解运算化设计的必要性，我们可以继续形而上学地认为计算机仅仅是一种工具。我们可以继续对设计的诞生进行诗意的描述，即设计源于设计师的大脑，就像神话中金星维纳斯诞生于土星朱庇特头颅中一样。毋庸置疑，程序的致命弱点是无法实现人类直觉所能实现的，这并不是因为它们没有直觉（它们也不必有），而是因为设计师只是在简单机械地使用，而非创造性地使用它们。

我并不回避这个问题：缺少了计算机，设计的许多方面仍然可以很好地展现出来。这些方面并不属于运算化设计的阵营，毕竟运算化设计并不能替代设计，而只是在新务实的环境下延续设计、拓宽设计。设计目前面对的最大挑战在于运算化形式下缺少新的设计知识，造成千篇一律的解决方案。哈伯望远镜的设计和它后期的修理，可以在仍有缺陷的状态下就被发射出去，开始它围绕地球的旅行。这依赖了运算化设计模型（主要涉及虚拟现实的方法和手段），它能够发现那些致命的设计错误，也可以生成包括完成特定任务的工具设计在内的、对其进行优化改进的程序步骤。这就是运算化设计不仅引入建模、渲染、动画，还需要模拟（包括虚拟现实）的原因。这仅仅是运算化设计的一点点成果，但足以让我们想象，利用综合运算化设计完成的数字化模型，比起简单的塑料模型、木质模型或是3D模型，意义大得多，更何况它仍在不断向前发展。在沟通层面上来看，实物模型在设计表达的即时性上有出色的表现，但是它的生产过程，同把实际建筑缩减到一个模型一样，贫乏可怜。迅速发展的原型理念远远比其他模型手段更先进。无论是利用CNC工具，还是简单的立体印刷技术，运算化设计都能让设计师对设计进行有效的评估，而这一点在机械制造厂房是不可能达到的。尽管有些设计师和建筑师仍然雇用好的木匠来完成模型，然而设计与工具已经由网络连接起来，我们可以利用虚拟现实或物理3D模型完成远程原型设计。

5 什么是原型（Prototype）？

为了更好地阐述设计的应用，我们需从一个基本概念谈起。设计在很多场合下，其实并不是为了制作真正的东西，而是先设计原型，再转变为真正的产品，比如报纸、自行车，或是一个新的时尚路线。以前，生产线很长，设计线就相应的很长。但现在情况已经不同了，我们生活在一个日新月异的时代，更强调“就趁现在”或是“即时市场”。从最初的设计理念到运输、发行，时间大大缩短了。设计与生产相互独立。过程简化会带来一些风险。

在设计阶段之后的快速原型制造，也成为运算化的组成部分。在这方面，平面设计师又一次走在了前端，他们最先利用数字技术的“快速原型制造”进行打样和印前测试。各地服务部门都可以远程执行从排版设计、校色到印前设计的工作，使设计师从“艺术家”走向了客户端。近些年，已经出现了纺织原型的“虚拟织机”，为产品开发组建的快速原型制造服务部门也相继成立。圣地亚哥超级计算机中心对网络远程原型制造提供了相应的技术支持。

当然，相对于传达设计和材质设计的打样阶段，工业设计中的3D原型技术要复杂得多。比如，要驱动激光打印机，需要生成“后脚本”（Postscript）文件，但是我们往往不知道该如何做好驱动快速原型制造设备的.STL文件（该类型的文件会把模型表面转变成为三角面网），为构建3D模型服务。快速成型技术最初是作为数控机床切割消减的程序，就好比雕塑家处理大理石或者木材中多余的部分一样。另外一个应用是立体打印技术（适当光照下液态感光），与消减性技术不同，它是一种添加性的装置，分为选择性烧结（利用激光束融合热塑性粉末）和雾滴性沉积（在薄陶瓷层或金属粉末上添加粘合剂）两种。我们也可以将添加技术和消减技术相结合，就好像熔融沉积模型（融化热塑性材料在由设计的形式进行“打印”）和层压实体制造（通过层层成型然后压合得到层压物体）。

显然，设计师并不需要是热塑性融合或立体打印技术的专家。他们了解计算机辅助设计及快速原型制造技术的原因是，设计表达与加工制造（计算机辅助制造）的关系越来越紧密。而且，设计师也必须认识到正是由于这项技术的出现，设计任务已经由最初的从已有形式中选取，转向了发明新的形式，设计新分子、新基因、新材料，甚至是和人互动的新形式。事实上，运算化设计的背景下，设计需要完全融合审美需求与功能要求，形式不再跟随功能，而是成为功能。为了达成这个目的，设计师不再仅仅作为订单和美学的代理人，不再把以前的那些“脏活”留给工程师去做。

我还想提一下“理想化”这个词，主要考虑到很多设计师还保有怀旧情结。我要强调的是，实际上理想的运算化模型，是各种特征都可以通过可变参数模拟出来。有人把这看成是运算化设计的缺点，但我却反而觉得这真是运算化设计的强项。过去，模型只能展示出在选定材料前提下的有限的形式特点；但运算化设计却能够体现多种可能合适材料的形式可能性，让设计师超越固有的限制。那些对数字化表述持怀疑态度的人，其实是没有认识到人类活动的主体，是处在认知的理想领域之中，而不是仅仅满足需求的层面，后者会限制某些新技能的培训（体现在仍然使用昔日的机器和工具上）。

6 设计与希冀

作为创意主体的人类，最大的强项并不是对外在世界和自然变化的反应，而是希冀（对未来变化的希望并为此做出行动，译者注）。运算化设计的本质就是希冀，即前摄性。换句话说，运算化设计强调，由未来决定系统现有状态的事实，定义的概念领域。这可能这听起来难以让人相信，让我们的思绪转向不是预言，就是技术。但是仔细想一下，我们就会意识到如果没有希冀的因素，那设计只能是一种被动跟随的游戏，一种对变化的消极反应，而失去了作为变化中介的角色。昨天那个决定性的口号——设计是一个解决问题的过程——依然萦绕于耳，以致我们难以确定是否已经真正实现了它，这简直就是一场游戏。形成鲜明对比的是不断的再包装（一系列基于同种元素只是风格不同的咖啡机、烤箱、汽车、收音机和计算机），运算化设计需要且支持发明创造。在环保意识日益加强的今天，运算化设计挑战了一次性解决所有问题的设计策略。通过问题生成，运算化重新定位了在当今环境和瞬息万变的社会生活中的个人。运算化设计平等对待个体与所处的环境文脉，并将最后终结大规模生产的时代，让人类进入一个提供个性定制化的解决方案的新时代。为了更好地解释这个问题，我需要再回到之前关于“实用(pragmatic)”的讨论中。

实用的大环境是对工作中某些特定的“力”、开发的能源和社会的政治结构的响应。史前猎人和强盗的设计需求、期望与农业和畜牧业时期的人肯定大不相同。即使在今天，因为设计定义了工匠和工厂劳工所处的环境和工作，他们同设计的关联，必定不同于教师、物理学家、科学家和艺术家那样。工业革命引起了许多同设计相关的问题，把世界变分成了许多不相关的板块。想想家里各种电器，或者办公室和工厂的各种设施设备，各自构成了围绕个体的“世界”本身，有自己的生活法则。信息时代带来的是世界一体化，把之前断裂的“板块”连成一个复杂而高效整体。设计只有考虑了人在各类不同环境下的差异，整合各种任务，才能更好地解决能源消耗、环境问题，更好地实现人与人的互动。

运算化设计也相应地为此构建出理论框架，并透过实践达成上述目标。显然，一体化带来了信息繁杂的问题。越来越多的按钮和按键，无论设计得多么优雅，我们还是很难掌握机器复杂的使用方法。因此，设计师应该通过设计，更好地控制复杂性。如今的情况就是，每个机器都只能发挥20%的作用。设计仅仅停留在玩味复杂的形式，并不能充分利用现有的技术有效地帮助用户解决问题。

7 设计与广泛存在的运算化

20世纪早期，电力的飞速发展与网络技术的普及，使得运算化设计不断推动全球经济的进步。电力、电话与电视构成了世界的底层结构。同样，数百万人已经通过各种事物，从网络数字互动及先进的运算一体化中获益。运算化在电话、无线通讯、手表、家用电器、汽车卡车、飞机、自动柜员机、娱乐和教育等方面都有体现。与运算化设计机密相关的数字化技术的各种应用，还都只是在起步阶段。运算化设计应该积极承担起加快进程的作用。一两个设计师决定用不用计算机进行设计无关紧要，普遍的变化并不以小范围的异议为转移。昨日许多设计师还在宣称抵制桌面出版程序，然而现在，尽管有些程序还是以前的状态，甚至有些显示出较大的缺点，但是一个众所周知的事实是，现实中没有程序使用技能的设计师在设计领域中，已经很难找到工作了。工作需要以及全球经济特点，都显示出如果我们能够认识到现在的实情，就会有更多的选择、更多的可能性。运算化设计的前景相当乐观。

在我们正在经历根本性变化的环境下，设计的新任务，源自人类务实的认知感，设计教育也会受到影响。因此设计实践与设计教育都需要做到前摄性，不能仅仅作为技术进步的反映，就是说要将运算化或其它形式的信息处理媒介，都变成设计的一个有机组成部分。简言之，在工作室或大学课程设计中，书籍、海报、宣传册、汽车、烤箱、椅子、台灯都可以作为设计的课题。相反，只知道如何设计这些产品，并不代表设计师有足够的应对新问题的能力。仅仅利用计算机来美化设计，把它当作传统表现工具一样使用，必然效果不大、不尽人意。在设计新产品时，电脑必须创造性地整合到设计的过程中。为此，整个计算机工业虽然一直竭尽所能在做，但却一直没有找到行之有效的办法。计算机行业的人，最多只能想道要在设计领域达成这个目标，必须有更快的芯片、更大的储存容量及更好的压缩方案，仅此而

已。因此，无所不在的计算机革命进程中，运算化设计将推动设计师成为计算机领域的合作伙伴。

功能主义的思想仍然回响在运算化设计项目中。抛开办公桌上笨重的设备，远离人人变成打字员的苦恼，运算化的普及，提出了与各类无形的数字设备互动的新观点。运算化取代了对更好界面的迷恋，通过计算机的集成能力，在提供实现人类公平和任务合理的设备与工具方面，可以更好地表现。和任务脱离的计算机应该引起我们额外的关注，因为只有重新和任务的目的联系，数字化技术才能充分实现我们的意愿。运算化设计的主要目的就是让信息处理集成能力，成为人类能力和思想的有效补充。要有电灯泡，并不需要知道电厂如何工作，也不需要了解如何处理变压器；要使用洗衣机也不用考虑那些集成运算；要获得天气预报、旅行援助和游览信息，也是如此。新产品、新汽车、录像机、家具的设计都应该了解用户的需求，医疗设备应该同时为护士和病人所有，甚至各种智能工具，也应该所有人都可以操作的。运算化就应该像运动鞋一样，穿在谁的脚上都能很舒服。我们应该信手拈来直接使用，不需要什么过多的培训或者教材。其接口使用界面的设计是运算化设计的关键，这点应该是显而易见的，界面设计一定是运算化设计的重要组成方面。而界面设计同设计本身一样，是无形的，与设计的对象和信息形成有机的整体。在技术飞速更新换代的今天，目标决定了设计的主要任务。

8 设计研究：变化的动力

随着运算化设计的出现，设计迈入了一个划时代的新世纪。作为建立人类活动新务实大环境的参与者，设计革新可能进一步分化我们的工作。因此，权利开始下放，等级结构也逐渐消失。设计领域内早就开始了这样的变化，虽然没有我们想象中的那么顺利，但已逐渐显现出一些效果。还有更多的变革即将到来，也许过程会更费力，但会影响到整个行业，因为过程中需要寻求更高效的水准，以维持和给养全球经济。我们所处的时代，变化的速度与创新的速度持平，设计师不得不走到最前沿。这也正是为什么延缓的策略，可以在变化缓慢的社会里生存，但今天必然不能奏效。那些不能适应快速变化的手段和方法将最终被淘汰。坏消息是，当今的竞争环境下，设计领域的破产率空前的高；好消息是，越来越多的革新派设计师，开始以各种形式运用运算化设计，在激烈的市场竞争中找到解决之道，成为进程中的标兵。昨天还是格林威治一个普通的小商店，今天就可以利用新媒体、新材料、新交互形式提供各式的服务。名片和办公用品的设计师，某天被那些酒店大堂、公共汽车站和火车站里的投币机取代，也不会让人大跌眼镜。新设计将越发关注人类的心智。网站可能不是个人能拥有的最高目标，但是如果站在人类正在空前的彼此链接、互动合作的层面上，网站要远比那些高级汽车、灯具或者明信片上为文盲阅读的白痴般的文字，更有意义。

随着运算化设计的到来，设计终于可以破天荒地确立属于自身的研发领域，不再需要等待其他学科的发展和需求。运算化让设计研发本身变成一股新变化的力量。

Knowledge is becoming increasingly computational. Previous means and methods for the acquisition, communication, and criticism of knowledge are being replaced by inquiry, dissemination, and evaluation carried out by digital means. Pascal, Leibniz, and Peirce, among others, prepared the conceptual framework for this fundamental change. They asked questions regarding our motivation to know, our way of acquiring knowledge, and our desire to share it. In other words, they defined the cognitive horizon. Closer to our time, Boole, Wiener, and von Neumann provided the scientific foundations. Finally, Atanasoff, Zuse, Eckert and Mauchly (among others) built the machines. The rest is already part of our lives: computer graphics, visualization, desktop publishing, CAD, multimedia, virtual reality, Internet, World Wide Web with more to come. In the process, sciences became computational: physics, biology, chemistry, to name the best known. Many engineering endeavors took the same turn with the synthesis of materials, robotics, even the production of computers, and the automatic generation of software. What happened to design in this context of fundamental change?

A Snapshot of the Current Situation

As things stand, computers and design are merely an association of tools and users. Indeed, within the design community, the discussion still goes on whether the computer will ever replace the designer, or if it will at least replace the pencil and the marker, not to mention the tedious process of model building. Graphic designers are very much ahead of the rest, plowing happily in the new territories of typeface design, print on demand, and electronic publishing. They discovered very quickly that digital technology means not only better tools for old functions, but also a broadening of the scope of their activity. The laser writer, the scanner, the plotter, the compact disk, and more recently network tools (browsers, applets, frames) were integrated in a new practical effort. So were the methods and means of science sampling, splicing, mutations, hyperlinking. As a result, printed paper is complemented by multimedia and Internet-based communication. Exemplary of the effort I am referring to is also the new practice of communication design: the virtual design office. Indeed, in this case designers designed their own new context of interaction based on the technologies and the methods they work with. Thus the computational becomes constitutive of the work, and is tested as the work itself is subjected to evaluation. But even in graphic design, fundamental issues are still avoided: Do we address a generic human being, who has remained the same as science and technology have changed? Or do we "design" our own public, i.e., invent forms and means for more individualized, and still socially rooted, forms of human interactions? How do we transcend the dominant obsession with mass communication (broadcasting) and make narrowcasting a design goal equally significant in respect to contents and expressive means? Do we improve on what we inherited or do we participate in the renewal of the motivations and means of communication?

Technology, even as it is creatively applied in communication design, is still ahead of us. In other design activities, and primarily in what is called product or industrial design, the situation to date is less promising. While the old-fashioned industrial design practically stopped generating employment opportunities, educational programs are slow in acknowledging the need for integrating the digital. The educators involved still think in the solid terms of the model of the Industrial Revolution, terms that are based on formal expectations of crafting but not on the need for new design thinking. As we know, the investment in technology hardware, software, maintenance, training, research of new avenues is prohibitively high. Few have dared to take the risks of entrepreneurship, and even fewer have succeeded. Big companies consolidated their controlling positions, and literally sucked in everyone able to manage the complexity of computer-based or computer-aided design. In many cases, instead of making design more transparent, they insulated themselves under the very convincing argument of protecting intellectual property instead of disseminating it. It is not unusual that advanced product design teams using advanced computers and sophisticated software do not even have access to the Internet. While those involved in digital technology attempt to produce viable methods of cooperative design work, such teams are predicated to a monastic type of activity. More often than not they do not even notice the contradiction between the means used and the methods and structures of work. Consequently, they maintain the secrecy (of new car models, new toys, new furniture, etc.), but are always late on the market.

Technological lead over design considerations is radical not only in the area of industrial design. It is also manifest in textile, fashion, toy, and interior design, all forms of design still close to the paradigm of craftsmanship. Consequently, monstrosities of all kinds, conceived with the aid of some computer programs, spill over to the consumer in the supermarkets of discounted bad taste. No matter how "noble" the intention of making affordable every gadget that until now was in the exclusive realm of the military and the intelligence communities, it only rarely justifies their presence in our culture.

About the Possibility of Design Theory

Computational design acknowledges the association between tools and users. However, its goal is to turn this into an association of new possibilities, which should become realities through design. To achieve this goal, computation cannot be only, as it is today, a medium of representation and unsystematic, or even systematic, variations. It has to become constitutive of design. This brings to the forefront the older question of whether design theory is possible, and if yes, which form it can take.

In the past, to the extent it was formulated, theory has followed the practice of design. The best designers, or at least those able to articulate their thoughts in writing, rationalized their achievements; that is, they discussed what they did and how only after their design was acknowledged or received public acclaim. This situation should not surprise anyone. Design evolves, as we all know, from the crafts and in this evolution, it first has to acquire legitimacy among many other human endeavors. But as it develops its means and methods, it also produces its justification and conceptual horizon. With the emergence of design criticism and design history, obviously in connection with the establishment of design education, the possibility of theory is established. Such a theory had to be analytical at the beginning. In time, induction acquisition of knowledge through observation was complemented by deduction derivation of new knowledge from design generalizations. As a result, design theoreticians were able to venture into synthesis. The example of the Russian Constructivists, or of the Bauhaus, or of American design after World War II belong to the domain of new concepts. Some were adopted from morphology, structuralism, semiotics, and even from psychology, linguistics, sociology, and engineering. Others were derived from within, the best example being functionalist design. In recent years, algorithmic thinking, heuristic procedures, and even genetics found their way in the theory of design. Moreover, design hypotheses were computationally modeled and tested. My own Design Machine™ can be mentioned as an example in this direction.

Theories attached to discursive reasoning remain captive to the deterministic equation: there is a cause, i.e., design work, and there is a result, i.e., designs that become identifiable objects traded or culturally recognized for their characteristics. So it ought to follow that a theory should explain how people design and what good design is. Here things get murky. First of all, because language as we know it might be the best medium for our reciprocal understanding, but not necessarily for handling human activities that by their nature are not reducible to language. Second, because the romantic assumption within discursive reasoning is that good design "good" being defined in a given context (formal, functional, structural, etc.) is also successful. Obviously, a good design theory should explain why sometimes this is not the case. As this kind of questioning in and with the help of language is established, we have learned that design theory is inter- and transdisciplinary. These are good words to use in applying for a grant, but not necessarily helpful in practicing design theory, or in designing. Nevertheless, the result of this understanding explains the import of specialized language in design. Ergonomic, functional, psychological, sociological, and economic concepts invade the dialogue on design issues and the curriculum of design education. Designers speak to future clients more about ergonomic, cultural, or symbolic aspects than about design itself. More recently, the language of lawyers is being added to the wholesale package of design theory, since the practice of design also means protecting its products in a society inclined to protect the written, but not necessarily the more ambiguous visual expression.

A Design Knowledge Base

Computational design escapes this Catch-22 situation. It is, like any other form of computational knowledge, anchored in the pragmatics of human existence. As we know, computational physics is at the same time theory and practice. As theory, it produces hypotheses regarding the beginning of the universe, for example. As practice, it simulates them in order to test the validity of the premise, and it eventually transforms them into new tools for the investigation of the universe. Simulations serve further to derive new knowledge regarding our inquiry of the universe. They also help us to understand the meaning of this knowledge for our own activity, regardless of whether we are physicists or professional involved in other fields (biology, chemistry, philosophy, art). Such knowledge is proactive, in the sense of opening new avenues for practical endeavors. Think about the many experiments with plants, animals, food or even with art performed in outer space. Computational engineering synthesized new materials some very interesting for designers and as a result also opened new avenues towards the future. It starts from hypotheses at the molecular or atomic level. Its results are the new structures modeled and tested in computational form before any other natural resources are processed. Computational genetics is a practical activity having at its center human well-being.

Computational design means, then, design activity driven by the forces that make design possible and necessary in the first place: assessment of needs, assessment of possibilities, assessment of means as they embody human characteristics. The assessment takes the form of data, in particular, complex databases. But while any other design theory is by its nature reactive, based on opinion, and thus often speculative, a computational design theory is based on processed data and is by its nature proactive. Its limits are the limits of our ability to collect and meaningfully organize data regarding quantity as well as quality, and our ability to design effective computational procedures for their processing. Like any other computational theory it is at the same time practice, more precisely design practice in the broader context of extremely differentiated forms of human activity, such as those we experience today. It is subject to confirmation by test, and it is, first of all, centered on knowledge, the most important asset human beings have. Accordingly, it requires that we establish a design knowledge base that extends beyond the poor, or even less than poor, design museums and collections, books and articles about design. Furthermore, it requires that we design procedures for navigation, search, and retrieval in such a knowledge base, evidently conceived at the global level of human existence today. Artifacts, along with the plans and designs from which they were derived, need to be seen together from a broad cultural perspective. Such a knowledge base should also contain computationally expressed knowledge regarding visual representation, movement, color, ergonomy, the integration of other means of communication (sound, texture, smell, etc.). All these objectives are a tall order, but unavoidable. Unfortunately, the majority of our design museums and collections, the places where we look at design as a "school of the past", resemble a junkyard more than a knowledge base for design.

As examples of what belongs in our design knowledge base, as it started to become a reality, are the computer programs that the design community uses. Indeed, a CAD program, or one for the production of a new font, a multimedia composer, or a net browser is already a theoretic expression of high abstraction. Within such a program, we describe geometry, material characteristics, optics; we describe movement, perspective, associations of images and sounds, ways to integrate text, and many other components of design. Not all of them are captured together in such programs, of course, but at least those about which a design consensus has been established. Or those we understand better. The practice of design based on such "theories" is, then, the research of actual design assignments. And the evaluation of the design is the performance of the artifact digitally conceived. In successive versions, benefiting from the experience of design such programs improve. As I write these lines, Netscape™ 3.0 is being announced; it will integrate teleconferencing, which makes my next statement self-explanatory. In the succession of design hypotheses, some disappear because the theory they advance proved inappropriate. Only two years ago, teleconferencing, a major communication design idea, was a potential multibillion dollar market. In our days, it is becoming a standard browser function.

Let me make the idea of design as program more clear: The Macromedia Director™, or the Phontographer™, or Alias™, or Vellum™, or those programs used for desktop publishing (Quarkexpress™, Pagemaker™), for textile design, for jewelry, etc., are programs we can buy in stores and use for particular jobs. But as opposed to the pencil, brush, exakto knife, wood or metal type, composer stick, etc. that designers used in the past, such programs are condensed theories of the activity they support or invent (as was the case of teleconferencing). None describes design completely. They describe and synthesize design activities related to our interest and need for multimedia, font design, or for CAD, for publication design or for on-line advertisement. Those who authored such programs, quite often large teams of programmers, psychologists, designers, etc. integrate in them knowledge of physics, mathematics, aesthetics, semiotics, of ergonomy, etc. In fact, each such program is a theoretic hypothesis. Those using them test this hypothesis. The products that are finally generated are comparable to the products that result after computational engineering is applied for creating new materials, or computational genetics for creating new medicines.

Computers Are NOT Only Tools

In fact, new materials, new medicines, and new genes are designed. I use this term to suggest that design is becoming a very broad endeavor in the age of computation. If we do not understand the necessity of computational design, we only continue the metaphysical talk about how computers are only tools. Or we continue the poetic description of how design originates, like Venus from the head of Jupiter, in the head of designers. Or how intuition explains what indeed some programs still cannot achieve, not because they do not have intuition (which they don't have to have), rather because in using them, we are not yet as comfortable with them as to use them creatively.

Let us face it: many aspects of design can be carried out perfectly without any use of computers. Such aspects are not really the object of computational design. After all, computational design does not replace design, it continues and broadens design in a new pragmatic context. The real challenging aspects of design in our times are exactly in the realm where without the new design knowledge in its computational form, we could not come to viable solutions. Consider the design of the Hubble telescope, and consider further its fixing, after it was launched in a defective state and started its journey around the earth. It was in a computational design model, involving means and methods of virtual reality, that the design error that almost rendered the telescope useless was diagnosed and procedures for improvement, including design of tools appropriate to the task at hand, generated. This is why computational design integrates modeling, rendering, animation, but also simulation (including virtual reality). That this level is only timidly reached should not prevent us from understanding that the digital model resulting from a comprehensive computational design work is infinitely more telling than the Styrofoam, or wood, or polymer 3D artifacts that so many continue to idealize. As conversational pieces, models convey a beautiful quality of immediateness. However, for the production of the real objects, they are as poor as any reduction of the real to a model. Moreover, the emerging rapid prototyping is far ahead of any other modeling endeavor. Whether driving CNC tools or even performing modest stereolithography, computational design allows a designer to reach a level of evaluation that is not possible in the mechanicâs shop. Instead of hiring a good carpenter, as some designers and architects still do, we can perform, even today, remote prototyping either in the form of virtual reality or in physical 3D. Design and tools can be connected via networks.

What Is a Prototype?

In order to clarify the design implications, let us start with a conceptual framework. To design is not to make the "real" thing, but the prototype of what will become, for example, a newspaper, a bicycle, a new fashion line. In previous times, when production cycles were long, design cycles were also relatively long. This situation has changed. We live in a day-and-age described by "just-in-time" or "time-to-market." From concept to shipment and distribution, time has been reduced by many orders of magnitude. The design process and the fabrication process are interdependent. With the risk of some simplification, generic diagrams give an idea of the process.

Rapid prototyping everything following the design phase as a computational component, deserves at least some words of explanation. First of all, graphic designers were again in the forefront since they started "rapid prototyping" by using digital technology for proofing and pre-press evaluation. Service bureaus all over the world perform, remotely, everything from typesetting to color correction and pre-press functions all that it takes for a design to make it from the "artist" to the client. In recent years, textile prototyping on "virtual looms" became possible and rapid prototyping service bureaus for product development started opening, too. The San Diego Supercomputer Center supports remote prototyping on the Internet.

Sure, prototyping in 3D, for industrial design purposes, is a more complex enterprise than proofing for communication design, of for textile design. We know how to generate good postscript files to drive laser printers, for example. But we are far less good in generating the so-called .STL files that drive RP devices. Such files employ a surface representation defined by triangles and serve in the fabrication of 3D models. RP technology started as a subtractive process a numerically controlled (NC) machine chiseled away, pretty much like a sculptor does working on marble or wood, what was not necessary. Today it offers additive mechanisms in the form of stereolithography (liquid photopolymers solidify under the appropriate light), selective sintering (the fusing together of thermoplastic powder by using a laser beam), droplet deposition (laying down of an adhesive liquid over a thin layer of ceramic or metal powder). We even have a combination of additive and subtractive processes, such as in fused deposition modeling (the melting of a thermoplastic material and its further "printing" in the designed form) and laminated object manufacturing (a laminated object is processed from layers of paper).

Obviously, designers do not have to be experts in thermoplastic fusion or in stereolithography. But they need to think in terms of computer-aided design (CAD) and rapid prototyping (RP), because the connection between representation (in design) and actual fabrication (through computer-aided manufacturing CAM) is getting tighter. Moreover, they need to realize that due to such technology, design tasks shift from the traditional expectation of giving form, of Gestalt, to inventing new forms, some as exotic as the design of new molecules, new genes, new materials, new forms of human interaction. Indeed, in the computational design context, aesthetic considerations and functional characteristics need to fuse. In order to accomplish this goal, designers can no longer restrict themselves to being agents of order and beauty, leaving the "dirty job", as to how things work, to engineers.

Having mentioned the word idealize in reference to the nostalgic view some designers still have, I need to confirm that, in effect, the digital model is in the realm of the ideal, where characteristics are simulated and can be optimized by varying many parameters. Some see here the shortcoming of computational design, although it is its strength. In the past, models could only display characteristics of available materials. Computational design models make the question of appropriateness of materials possible. They challenge the designer to go beyond what is available. Those who feel insecure about the ideal nature of the digital representation fail to realize that the majority of human activity is in the ideal domain of the cognitive, not in the necessary, but somehow limiting training of skills (quite often on machines and tools of yesteryear).

Design and Anticipation

The strength of the human being, as a creative entity, is in anticipating, not in reacting to the outside world and its natural changes. Computational design is by its nature anticipatory, proactive. In other words, it addresses a conceptual realm defined by the fact that the current state of a system depends on its future. At first, the thought sounds dubious. It brings to mind predestination, or teleology. But once we consider the idea, we understand that without the planning element, which is anticipation, design remains a catch-up game, a form of reaction to change, instead of being an agent of change. Design as problem solving, the slogan of a deterministic past so close to us that we are not sure whether we have overcome it, was such a game. In contrast to continuing the line of a practice of re-packaging (all the series of coffee machines, toasters, cars, radios, and computers, based on the same components but stylized differently), computational design involves and supports invention. It challenges the once-and-for-all solution, especially in view of an increased ecological awareness. It generates problems as it takes an active role in repositioning the individual in our environment and in an extremely dynamic social life. It does justice to the individual and to the particular context of existence as it brings mass production to an end and facilitates customized solutions. To explain this component, I need to briefly revisit previous pragmatic contexts.

Pragmatic contexts correspond to specific forces at work, energy sources tapped, social and political structures. The prehistoric hunters and foragers had design needs and expectations very different from those of the humans involved in agriculture and animal husbandry. Craftsmen and factory laborers, even in our day, relate differently to design as it defines their living environment and their work than do teachers, physicians, scientists, artists. The Industrial Revolution posed many design problems. It also broke the world into many unrelated pieces. Think of all the appliances in one's home, or of the many tools in our offices and factories. Each makes up a world in itself, with its own rules for performing appropriately. The information age brings about the possibility of integration. Issues of energy consumption, environment, and better human interaction, issues of cultural diversity can be better addressed if we design with the aim of integrating human tasks without ignoring the differences among people living under different conditions.

Computational design should accordingly constitute the conceptual framework for such a task and become the practice of accomplishing it. Evidently, as integration takes place, we have problems in dealing with complexity. More buttons and more keys, no matter how elegantly designed, do not help in our command of the new complex machines. Accordingly, designers need to work on giving through design a better control of complexity. Otherwise, each wonderful new machine will only be used to 20 percent of its actual capacity which is the situation today. Design stuck on formal considerations does not effectively help users get the most out of what is technically possible today.

Design and Ubiquitous Computing

The expansion of computation through networking, which contributes to the dynamics of the global economy, and through ever increasing performance parallels the deployment of electricity as it took place earlier in the 20th century. Electricity, telephony, and television form an integral part of the underlying structure in many parts of the world. Similarly, millions of people already benefit from digital interaction through networks and from the progressive integration of computation in human transactions of all kinds. Computation is integrated in the telephone, in many services associated with wireless communication, in wristwatches, in home appliances, in trucks and automobiles, in airplanes, in automatic teller machines, in entertainment and edutainment. Compared to the state of computation, the creative use of digital technology is only at its beginning. Computational design should assume the goal of actively speeding up the process. It is irrelevant whether one or another designer decides not to use the computer. The dynamics of the process is such that the broader change does not depend upon such decisions. Many designers resisted the change announced by the desktop publishing programs of yesterday. As primitive as some of these programs were, and some failed in the meanwhile, they opened a new horizon and led to a reality expressed in the simple fact that those who do not master such a program cannot find a job in the design industry. Forces at work, characteristic of the global economy, define further directions which, if acknowledged and properly understood, allow for more variety and the unfolding of more possibilities. The underlying dimension of computational design is optimism.

The new tasks of design in the context of the fundamental change we are experiencing result from the recognition of the new fundamental pragmatic condition of the human being. The tasks of design education cannot be less affected by this condition. Therefore, to practice design and design education proactively, not merely in reaction to technological developments, means to make the medium of computation, and any other information processing medium, part of design. In short: not that books, posters, brochures, or cars, toasters, chairs, and lamps are invalid design subjects, in the studio or in college education. Rather, knowing only how to design such items does not prepare a designer for those qualitatively new problems we are facing. To use the computer for design cosmetics, doing what traditional tools can do just as well, is unproductive and unsatisfying. The computer has to be creatively integrated in the design process, in the new products designed. This is something the computer industry does not know how to do but is trying desperately to achieve. Those who work in the computer industry know that faster chips, more storage capacity, and better compression schemes are only means to a goal that is fundamentally in the realm of design. Accordingly, computational design will make designers become partners in the ubiquitous computing revolution.

The functionalist thought is echoed in the ubiquitous computing design program. Instead of the bulky machine on everyoneâs desk, and instead of turning each user into a typist, ubiquitous computing offers the perspective of natural interaction with many "invisible" digital devices. It replaces the obsession with better interfaces, as a hope for better user performance, through integration of computer capabilities in appliances and tools that do justice to the human being and to the task at hand. A computer isolated from the task at hand requires excessive attention. Once reconnected to the purpose, digital technology enhances our ability to fulfill the purpose. The integration of information processing capabilities in ways that complement people's abilities and their ways of thinking is a major goal of computational design. In order to benefit from the electric bulb, one does not have to learn how a power plant works, even less how to operate a high voltage transformer. The same should be the case for people using active maps to obtain weather reports, travel assistance, or tourist information. Or for those using the new washing machine that integrates fuzzy logic computing. New products cars, VCRs, furniture that "learn" the behavior of the user, hospital equipment that assists the nurse as well as the patient, intelligent tools of all kind, should not require a college degree to operate. Computation should fit us as comfortably as a pair of sneakers. And we should be able to use it when necessary without having to study volumes of printed matter or to go through extensive training. That interface design is a major aspect of computational design should be obvious. Less obvious is the fact that the best interface design, like design itself, is invisible, i.e., integrated in the object or message designed. These are goals that define design tasks in a context of fast technological renewal.

Design Research: a Force for Change

With the advent of computational design, design enters a new phase of its remarkable history. As a participant in the establishing of a new pragmatic framework for human activity, design innovation makes possible distributed work. Accordingly, it contributes to decentralization, and to the disappearance of hierarchic structures. Within the design community such changes already take place, not always as smoothly as we would hope for, but definitely with the effect of a higher sense of responsibility. Much more will take place, and probably even more painful changes will affect the profession as it seeks its justification in a society determined to achieve levels of efficiency high enough for the sustenance of the global economy. As we reach the time when the rate of change equals that of innovation, designers are forced into the forefront. This is why procrastination, a survival tactic in times of less fast change, will not do. This is also why means and methods not adapted to these fast cycles of change fail. The bad news is that in the competitive context of today's world, the bankruptcy rate in design is higher than ever. The good news is that more and more innovative designers, definitely aware of computational design or practicing it in some form or another, make their way in the competitive market of innovation and become icons in the process. Where yesterday in Greenwich Village were the gadget shops, today design shops offer a variety of services based on new media, new materials, new forms of human interaction. By no accident are the designers of business cards and stationery replaced by coin-operated machines placed in hotel lobbies, bus depots, and train stations. New design addresses our minds more and more. Maybe a Website for an individual is not the highest goal one can have, but to think in terms of human interconnectedness and cooperative effort is of a higher order than to stylize cars, lamps, or to produce idiotic messages on postcards for illiterates.

With the advent of computational design, design finally defines its own domain of research and development. As a result, instead of waiting for other disciplines to define its agenda or scope of inquiry, computational design makes design research a force of change.

注释:
Note:

①Boole, George. (1815-1864) conceived of a logical calculus in An Investigation of the Laws of Thought on which are founded the Mathematical Theories of Logic and Probabilities (London, 1854).

②von Neumann, John, the legendary mathematician, was also instrumental in the paradigm of sequential computing. He was aware of the ENIAC (Electronic Numerical Integrator and Calculator) built by J. P. Eckert and John Mauchly) and in 1945 wrote the famous First Draft of a Report to the EDVAC (Electronic Delay Storage Automatic Computer).

③Regarding the Design Machine (a research project carried out in 1985-1988).

④Regarding Anticipation.

⑤Nadin Mihai. Mind Anticipation and Chaos (German-English parallel text, from the series Milestones in Thought and Research)[M]. Stuttgart/Zürich: Belser Verlag,1991. Develops a cognitive model based on chaos and anticipation.

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[3]Rosen Robert. Anticipatory Systems: Philosophical, Mathematical & Methodological Foundations[M]. Oxford/New York: Pergamon Press,1985.

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