A New Building Culture
Towards a Radical Confrontation between Data and Physics
一种新的建筑文化
走向数据和物理间的激进对抗

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当今世界建立了一套完整的建筑技术基础体系，从其发展伊始——20世纪中期建筑工业化就比现实更具想象力。我们将见证的不再是现代化进程上的一次产业发展的滞后，相反，却是一种历史意义上的分界：脑力劳动与手工生产，设计与实践间的现代主义意义层面的关系正被宣告结束[1]。与此同时，大量的建筑内容在主体内容中重新回归，不仅仅是手工工艺和建造的艺术，尤为突出的是建筑设计的方法。随着机器人在建筑学领域的发展，关于数字时代的辩题不再是20世纪90年代由克林顿提出的“去物体化”的时代性的悖论[2]，相反，如今我们聚焦的是建筑广泛的数字化进程，这在其生存条件下包含着一个激进的模式转换，正如我们近期出版的新书《机器人建造——机器人如何改变建筑学》。在建筑领域对机器人的应用完全开来新材料的研新愿景，而这一点从根本上改变了建筑设计和建筑文化[3]。

回顾历史

从20世纪90年代初期开始，从传统工业生产到数字化建造流程的过渡转变引发了一场影响深远的变革，引领了建筑生产环境的模式革命。如今，预生产工业技术已成为司空见惯的场景：过去，标准化一直是工业生产技术革新的推动力；而如今，所谓的“生产”——即生产某一特定商品——一跃成为信息时代的推动力。由于工业机器人可以执行无限能够的重复性任务，因此被认为是这一重大变革中的主要促成因素的其中之一。

Today, a uniform technological basis for architecture has been established, which from the onset of building industrialization in the early 20th century until now had been more a dream than reality. We are no longer witnessing the delayed modernization of an industry, but rather a historical departure: the modern division between intellectual work and manual production, between design and realization, is being rendered obsolete[1]. At the same time, a wide range of inherently architectural topics are finding their way back on to the agenda, not least among which are crafts and the art of construction, and, in particular, methods of architectural design. As robotics becomes increasingly commonplace in architecture, the subject of debate in the Second Digital Age can no longer be its "dematerialization into pure form", as had been proposed by digital architecture during the 1990s[2]. Instead, what we are observing today is the comprehensive digitalization of architecture, which entails a radical paradigm shift in its production conditions. As outlined in our recent book "The Robotic Touch – How Robots Change Architecture", the employment of robotics in architecture is thus opening up the prospect of entirely new material capacities that could fundamentally alter architectural design and the building culture at large[3].

Forward to History

Since the beginning of the 1990s, the transition from traditional industrial production techniques to digital fabrication processes...
has triggered a far-reaching change, which has led to a paradigm
shift in the production conditions of architecture. Now, nonstandard
manufacturing techniques have become commonplace. Just
as standardization has been the driving force for technological
innovation in industrial production in the past, so-called "non-
standard production"- that is, the manufacture of unique pieces-
functions as a driving force in the information age. The industrial
robot, because of its ability to perform an unlimited variety of non-
repetitive tasks, is considered as one of the key enablers for this
deep transformation.

However, rather than focusing on the technological development
of robots themselves, no matter how fascinating this might be, we are
interested in establishing an architectural perspective on them
by exploring the potential of robotic-induced design and materialization
processes. To this end, we have reverted to using articulated-arm
robots as established, cost-efficient fabrication machines that are
at once both reliable and flexible, and whose potential in conventional
industrial applications has been thoroughly proven. It is essential
that architecture and the conditions specific to its production inform
the approach to robotic fabrication, and not vice versa. Only in this
way is it possible to significantly expand the range of architectural
design and production options, enabling a new material
differentiation and complexity to emerge and feed expression.

In fact, the early introduction of robotic systems to the building
construction industry during the 1990s was anything but a success.
Most of all, the development of robot-based construction
processes frequently led to either highly specialized, extremely
cost-intensive construction robots with limited flexibility, or to robot-
based construction factories yielding the same constraints. Robots
in building construction up to this point were exclusively used to
further optimize (standardized) building processes, as a means of
achieving greater productivity. Ultimately, no real lasting added
architectural value, let alone any new (digital) building culture
took hold during these initial attempts at integrating robotics into
the building industry. All of this radically changed at the turn of
the millennium. Digital technologies became more commonplace
among the architectural discipline and began having a greater
impact on the understanding of architectural design and practice.
In addition, with the rapid spread of computer-controlled production
machinery borrowed from other industries, such as milling and laser
cutters or 3D-printers, the "digital project" attained considerable
"material value". In 2005, in order to examine the resulting new
production conditions for architecture, a multi-purpose fabrication
laboratory employing an industrial robot was installed at ETH
Zürich - the first such laboratory in the field of architecture.

**Authorised Additive Constructive Processes**

The possibilities for implementing constructive processes with
the robot are manifold. The robot can carry out a nearly unlimited
number of physical operations in space. Instead of being restricted
in its operations to a prescribed range of applications, the "manual
dexterity" of robots can be freely designed and programmed. Their
manipulative skill can be adapted to suit a specific constructive
intention, both at the material and conceptual levels. In contrast to
conventional construction procedures, however, the description
of these operations can no longer be achieved by means of
geometric depictions; rather they must be algorithmically denoted
and "recorded" through programming. The fabrication instructions
thereby produced - containing, for example, timing and building
sequence - are directly used by the robot for the spatial joining
of the materials. In comparison with subtractive and formative
techniques, this shift towards authorised additive processes allows
the aggregation of very complex and high-performing building
components out of basic materials. Furthermore, the structures
conceived in this way require less material than comparable
fabrication techniques to derive similarly refined constructions, simply
because the material is deposited at the exact location where it is

In 2005, a team of ETH researchers led by Professor Matthias
Bollinger designed and constructed a 3-axis robot that was able to
manufacture architectural components. The robot was operated
in an industrial robot facility and employed a range of different
manufacturing techniques. The results of this research were
published in a number of architectural journals and conferences,
and were subsequently exhibited at the Venice Biennale in
2008. The project received widespread media coverage, and
was subsequently published in a number of architectural journals
and conferences.

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the organization, this approach of single unitary components and their ensemble in a harmonious and unified whole.

The condition of building the mechanical layout is an achievement of design and construction, and this cannot be considered as organisational or sequential phases. Design and construction are incrementally interwoven as the design not only contains the knowledge of its overall structural configuration but also at the earliest point of its conception. Exactly here lies the essence of additive fabrication with the robot: the highly informed building elements can be built up at full scale while being contextually fabricated to their very core. The full use of the manufacturing capacities within specific constructive and structural conditions.

The Gantenbein Vineyard Façade represents one of the first projects to demonstrate this in an explicitly architectural context. It is remarkable how the central concept of additive robotic fabrication at full scale by demonstrating the non-standardized assembly of an extraordinarily large number of single (brick) elements with this characteristic can become clear why many of our projects build on supposedly simple, that is, generic, basic elements like bricks or timber slats. To the extent to which generic elements can be put together in various, highly informed and differentiated architectural assemblages, the application of the robot becomes not only meaningful but indispensable. Conversely, as soon as the individual elements become too specific through geometrical prescribed connections, their joining is largely predetermined, and constructive freedom becomes limited. The consequence is that sometimes such elements would be put together more easily and perhaps also more quickly by hand than with the robot; in these cases, the specific added value of the robot would be reduced to the pure automation of manual work processes. Indeed, all of our projects at ETH Zurich are usually distinguished by a large number of elements and their very detailed organization, a high degree of definition throughout, and simultaneously a distinctive coherence between the single elements and the whole.

The Neumann Scopes of Robotic Fabrication

We have since further expanded our explorations and sharpened our focus through a number of research projects. As such, the range of robotic processes is gradually expanding, from prefabrication towards the direct use of robots on the construction site and constructions at full industrial scale. For example, the Sequential Roof 568 showcases this investigation. Conceived as a 3,000 square meter large timber roof, this project radically targets an industrial scale, where more than 48,000 alternately layered timber components are automatically assembled into a full-size building structure. In contrast to bricks, this material allows the manipulation of its geometry during the fabrication process. The robot can easily cut each element to a specific length at any angle. The material customization enabled by this process—in which a generic, standardized industrial product is transformed into a specific and robust architectural element—results in additional degrees of freedom within the constructive system. This freedom allows for the realization of delicate structures in which plane surfaces can seamlessly merge with curved surfaces.

The explicit presence of The Sequential Roof results from the discrete layering of single timber elements in a continuously graded arrangement, which blurs the boundaries between the generic and the specific, the standardized and the individual, and therefore provokes a perceptive ambiguity. 569 Through programming the design is capable of responding to local requirements in a constructively flexible and specific way. By so linking the formal, constructive and fabrication parameters, an optimization of the entire structure can be achieved. Such systemic complexity can obviously not be managed by means of conventional manual design techniques. For instance, if only a single timber element of the roof construction is shifted, an endless number of relations in the complementary logic between geometry and tectonics, between the individual element and the entire structure, are changed. Here it becomes apparent that a certain "coupled mass" of construction components with mutual dependencies, the use of digital design and fabrication processes becomes not only meaningful but mandatory.

Essential here are also certain challenges with respect to fabrication logics and control, where multiple constraints evolve. On the matter of fabrication, on the one hand, these are physical constraints (e.g. load capacity, dimensions of processed parts, etc.), whereas on the other hand, these are also of economical nature (e.g. cycle time, reject rate, etc.). These constraints either have to be integrated already into the digital design process or have to be accounted when translating design data to fabrication data. Namely, the robotic fabrication process has to be structured into logic and efficient sequences so that a reasonable cycle time can be achieved at full-scale fabrication. Correspondingly, the design can no longer be encapsulated in a static plan. Rather it is described by a programmed set of rules, which advantageously allow for seamless adaptabilities, throughout and even at very late stages of the design process.

This becomes particularly powerful if this adaptability is consciously anticipated and deliberately parameterized by the architect. The intent is less a purely functional modus operandi of construction optimization than a focus on equally process-driven and structurally driven design methods, ultimately to strengthen architecture in its constructive/innovative character. Even though "The Sequential Roof" will only be completed with the new Arch_Tec_Lab building by 2016, the previous development has successfully demonstrated new dimensions of future robotic fabrication and provided a specific computational design and...
通过实际的实施过程分析，设计将需要清晰地了解一系列实施步骤，以便我们可以在具体实施过程的实施步骤中，对于“过程的形成”和“过程的控制”进行准确的分析，并对过程进行进一步的优化和改进。因此，对于过程的形成过程的控制和改进，我们可以通过对过程的形成步骤和过程的控制步骤进行进一步的分析和优化，从而达到改进过程和改进结果的目的。

在“过程的形成”中，过程的实施步骤通常是通过不同的过程控制环节来实现的，而这些过程控制环节则需要通过不同的实施步骤来形成。因此，通过不同的实施步骤的形成，我们可以对过程的形成过程的控制和改进进行进一步的分析和优化，从而达到改进过程和改进结果的目的。

通过实际的实施过程分析，我们可以发现，不同过程的形成步骤的控制和改进是可以通过不同的实施步骤来进行的。因此，对于过程的形成过程的控制和改进，我们可以通过对过程的形成步骤和过程的控制步骤进行进一步的分析和优化，从而达到改进过程和改进结果的目的。
物理化与新建筑类型

在建筑学中，物理化是指通过使用计算机和数字技术来设计和建造建筑物，使得设计过程和结果更加精确和高效。这种技术的发展使得建筑不仅具有美观的外观，而且在结构、功能和性能上都有着更卓越的表现。本文将阐述物理化在建筑设计中的应用以及其带来的影响。

随着计算机技术的发展，建筑设计已经从传统的手绘图纸转向了数字建模。数字建模技术使得设计师能够更快速、更准确地进行设计，同时也可以通过模拟和测试来优化设计，确保其在实际施工中的可行性和安全性。例如，通过虚拟现实技术，设计师可以在三维空间中模拟建筑的外观和内部结构，从而更好地与业主沟通，满足他们的需求。

此外，物理化还促进了建筑的可持续发展。通过计算机模拟和优化，可以减少建筑对环境的影响，例如降低能源消耗和减少碳排放。同时，物理化还使得建筑可以更加灵活地适应未来的变化，例如随着技术和社会的不断进步，建筑的功能和用途可以不断更新和扩展。

总的来说，物理化在建筑设计中发挥着越来越重要的作用，它不仅提高了设计的效率和质量，也为建筑的可持续发展提供了新的可能。在未来，我们期待物理化技术能够更加成熟和普及，为建筑行业带来更多的创新和变革。
Negotiating between Utopia And Reality

This becomes clear in the most radical way in the project Flight Assembled Architecture [18]. The project at the Fonds régional d’art contemporain (FRAC) Centre in Orléans represents the first architectural installation to be built autonomously by flying robots: several “Quadcopters” assembled over 1,500 elements to create a porous, tower-like aggregation [19].

What unfolds is a 1:100 scale model of an architectural vision for a 600 m high Vertical Village [20]. With a total of 180 floors, the urban structure provides living space for 30,000 inhabitants. The structure makes use of a grid-like organization that allows for a great degree of freedom in the variable arrangement of multi-functional modules. However, the grid does not run horizontally as in a conventional urban organization; rather it is turned vertically. Finally, both ends of the grid close to create a circular whole. Thereby the resulting cylindrical structure is not only self-stabilizing but also embodies a new type of spatially differentiated and programmatically diverse, dense urban organization.

Flight Assembled Architecture represents, above all, a technological intensification that introduces a radially expanded scope of digital fabrication. This results from the swarm-like deployment of the flying robots, in which they reciprocally adjust their operations and cooperatively build the Vertical Village. Correspondingly, the “Quadcopter” is used as an enabling technology and also serves as a “conceptual door opener” in order to make possible a radical architectural utopia that does not need to exclude its concrete material implementation.

In this regard, the airspace not only corresponds to a constructivist environment but also becomes a comprehensive design paradigm [21]. A sort of “suspense” results: between a physical architectural installation, which is being built almost over the visitor’s head, and its manifestation as a future utopia in the tradition of ideal cities [22]. Flight Assembled Architecture therefore fosters a revision of the city as a robot-built urbanity. At a scale 100 times smaller than the vision, the installation calls into question the supposedly clear line between utopia and reality. At the same time the boundaries between architecture and robotics become less distinct here, so that the “border between the thinkable and the feasible” is newly explored. Flight Assembled Architecture thereby expands the conceptual scope and constructive scale of robotic fabrication. Only by exploring the physical possibilities and the specific limitations of this technology will the architectural capacities of future robotic fabrication unfold.

Towards A Digital Building Culture

The situation today is Truly unique. Robotic fabrication provides the opportunity to expand substantially the material practice of the discipline and to renew the constructive knowledge of architecture from the inside out. In this context, such a constructivelogical approach understands fabrication with the robot as something that emerges from the treatment of material and the understanding of its constructive capacities, rather than material merely serving a predetermined form. Projects such as the Non-Standardized Brick Façade for the Gantenbein Vineyard, The Sequential Roof, Remote Material Deposition or Flight Assembled Architecture demonstrate this approach, be it through the layering of bricks or individually cut timber elements, the remote material deposition of deformable loam projectiles or through airborne construction. With such projects we mean to convey that the robot can act as a catalyst to impart cultural significance to digital architecture. In fact, it characterizes a seminal change in the production conditions of architecture, placing computational design in a close (creative) dialogue with reality. The robot can thus play a decisive role specifically because through it, the digitalization of architecture becomes physical and tangible [22]. This takes away the abstract and forces artificial character from the digital in architecture and imbues it with a distinct aesthetic significance and identity. Such a “Robotic Touch” thereby strengthens the inner competence of architecture, providing a consistent bridge between the planning of a project and its realization. The result is an increased consciousness that no longer originates from outside, through the favoring of formal exuberance and complexity, but rather from inside through the intensification of the creative, material and cultural expressive content of digitally fabricated architecture. And out of this grows a new contemporary digital building culture [23].