디지털 건축 디자인 연구

토니 코트니 | Toni Kotnik

연구 가능한 함수(Computable Function)

1963년, 이반 세첨레프의 스케치패드(Sketchpad)는 컴퓨터로 제어하고 모델링을 할 수 있는 기계를 보여주었다. 그의 한계와 그의 수학적 기여는 그가 제목을 가지고 기계가 적절한 주요 요소가 아니라고 하였다. 데이터 저작권의 영향으로, 소프트웨어는 컴퓨터를 디자인할 수밖에 없다. 이러한 기계 설명에서, 모든 데이터의 부분들은 비트의 운영체제(operating system)를 생성해 자연스럽게 움직이게 된다. 즉 프로그램은 자연스럽게 부분함수(parital function)이고, N의 부분집합 Par를 정의한 함수는 Par의 원소 n을 입력하면 부분집합을 통해 N의 부분집합 Par의 원소 ou를 도출한다((n) = ou(Fig. 1) 부분모의 기본값으로 보면, 컴퓨터를 사용하는 것은 항상 일관된 결과를 제공해 주는 함수 p에 필수적인 탐색을 의미한다.

위의 내용을 주제의 주제로써, 이는 우리가 컴퓨터를 사용하는 방법을 동일한 것으로 해석할 수 있다. 이는 CAD 소프트웨어를 사용하는 기계에 의한 모델링 작업에서 그 결과를 정의할 수 있다. 이러한 시스템의 모든 작업은 수학적 함수를 구성하는 세 요소가 결정된다. '단'의 요소는 '선택'의 경우 도구의 구성이므로 이는 함수 p를 변환할 수 있는 규칙으로 정의한다. 두 단계는 모든 가능성을 합친 방법으로 입력량(Par의 요소 n)으로 선택하는 것, 이는 그림 모양의 중심선 중 특정 두 점 사이의 선으로 모사되는 결과물(Var의 요소 ou)이다.(Fig. 1)

 컴퓨터다이나리의 과정은 도구로 동작하는 것은, 연속 가능한 함수를 디자인 도구로 하는 요소가 적절한 결과가 된다. 만약 간단한 정리, 다양한 방향성의 알고리즘 변형이나 설명함으로부터 선택하기 위해서는, 디자인과 과정에서 설명 가능한 기계를 '크로(-generating geometry)'보다 연속 가능한 함수의 집계적 논리가 더 중요한데 있다.

지난 십 년 동안 나는 DOCT(디지털 Chesire의 작업과 이론 저술, 학교(AD, ETH, 인스브루크대학과 설계건축학회)의 감독을 통해 연산 가능한 함수의 논리와 건축의 내재된 장점을 중심으로 디지털 디자인 연구를 진행했다. Par를 입력해 Var를 생성하는 형식을 비밀리어볼 수 있는 가정적 - 개념적 복잡도에 대한 새로운 디자인 연구(보상, 재역, 세계적 상호작용)가 가능하다.(Fig. 2)

분산(Variation)

건축 설계는 물질을 배합하여 조작적 공간을 창조해야 한다. 그러므로 건축에 형식적으로 접근할 때 가정적 요소와 운용을 종합한다. 나는 디자인 접근법에서 분산(Variation)에 의한 탐구를 연계성을 기반 가정적 운용 순서를 활용한다. 이런 순서는 조작적 공간의 연산적 순서 p로서 디자인 과정에서 이중으로 적용한다. 나는 ‘우리 집에서 나중 다리’ 프로젝트의 구성 요소의 U형이란 단단하게 볼 수 있는 가정적 관계 함수 p의 매개변수 n ∈ Par의 분산을 적용해 변하는 양의 상호가행에 따라 공간 운용을 적용한다.(Fig. 3) 이 프로젝트에서 구성 요소의 모양은 가정적 운용의 순서로 정의하고, 운용선을 따라 주어진 위치의 조정의 상대적인 위치에 끌어당겨 적용한다.

다음에서는, 입력 매개변수의 연속 분산은 가정된 공간 운용의 집합 Var의 원소가 된다. 공간 운용은 잘 알려진 유형학(geology)의 가정적 순서를 추정한다. 이 접근법은 바우하우스의 6자구 도시 마스터플랜 디자인에 활용했다.(Fig. 4) 이 프로젝트에서 주어지는 공간은 도시 구성과 농장이 있는 주택의 형태를 따라 다양한 공간의 형성과 사용을 가진 두 종류의 분산이 만들어졌다. 이는 도시계획의 기본 구성 요소가 되었다.

재귀(Recursion)
The Computable Function

In 1963, Ivan Sutherland’s Sketchpad program demonstrated that computers could be used illustratively, for both drafting and modeling. By the mid-1990s, it had become unthinkable to conduct an architectural practice without the inclusion of graphics software, and today, digital design technologies have been adopted almost universally as the predominant means of architectural procedure and production. Using the computer simply as a drafting tool, however, doesn’t by default signal ‘digital design’, as the design process is still in line with the visual reasoning of a conventional paper-based design approach. Digital design is about going beyond the merely representational.

Digital technologies have enabled new methods of design, leading to the current re-examination of design theory and educational platforms. In this sense, architecture is partaking in an “intellectual revolution” that is happening all around us, but few people are remarking on it. Computational thinking is influencing research in almost all disciplines, both in the sciences and in the humanities. . . . It is changing the way we think.” The computer however, as the main bearer of this “intellectual revolution,” is not part of the ongoing discourse surrounding the digitization of architecture. It is constantly overlooked; the machine and its functionality are relegated to a discursive blind-spot, little considered in their changeability. And yet, it is computers that actively shape the way we as users approach design questions. It was Merleau-Ponty who pointed out that we as humans must see our bodies not only as the physical context or milieu of cognitive mechanisms, but also as living, experiential structures that are both biological and phenomenological. A human understanding of the world depends, in the most part, upon the interaction of the body with its environment. Every tool necessarily mediates this interaction as a result of its particular attributes, thereby influencing the perception of the user and his way of thinking.

The starting point of my own investigation into digital design in architecture, therefore, was a more rigorous consideration of the basic functionality of the computer, paying attention to that which enables its versatile application. As a physical machine, computers have their origin in John von Neumann’s design principles for a computing mechanism, a set of directives developed from Alan Turing’s more general abstract conception of computation and the related idea of a universal machine. The versatility of a computer is built upon the generality of its main constituents: a machine, hardware, manipulating data according to a set of instructions, software. In this general setting, every piece of data takes the form of a finite sequence of bits, which is why it can be coded as a natural number. Thus, a programme $p$ can be viewed as a partial function on the set of natural numbers $N$, meaning a function defined on a subset $\text{Para} \subseteq N$ with output $\text{out} \in \text{Var} \subseteq N$ as the result of computation of the input $\text{in} \in \text{Para}$, that is $p(\text{in}) = \text{out}$. (Fig 1) Based on Turing’s model, this equation reveals that using a computer always means, without exception, the necessary limitations on computable functions $p$ as a mediator between input and output.

Such a seemingly abstract and theoretical description is a direct formal translation of the way one works with computers, a relationship which becomes obvious when drafting and modeling architecture using contemporary CAD software.

Every task in such a system is governed by the three components of a mathematical function: the activation of the tool, e.g., draw a line, as algorithmic rules of transformation that define the programme $p$; the selection of a pair of points as chosen element $\text{in} \in \text{Para}$ within the set of all possible pairs of points in space; and the resultant graphic output $\text{out} \in \text{Var}$, as the specific line between the points as out of the set of all possible lines. (Fig 1)

The purpose of integrating computers as tools into the design process, therefore, lies in the rigorous exploration of the defining elements in a computable function, manipulated as design tool. One must observe the formal relationship between sets of entities, the quantifiable properties of these sets of entities, and the algorithmic transformations and interactions between different quantifiable properties. As such, in this digital design process, attention shifts away from the form-generating geometry itself towards the logic of an underlying computational function.

It is this navigation within the logic of computational functions, and their underlying architectural potential, that has led my
Digital design is conscious utilization of computable functions, an algorithmic relationship between an input set and an output set. In most applications in architecture these two sets are defined by geometric entities like points, NURBS curves or surfaces and the relationship is given by a sequence of geometric operations.

Fig 1
The U-like frames of the bridge are developed through a sequence of geometric operations out of the relative location with respect to three focal points and the position along the three bounding curves. This results in variations of the frame which can adapt constantly to the changing local conditions of angles, height and step width.

Fig 2

Fig 3. Bifurcating Bridge. AA Emtech, 2010

Fig 4
investigation into digital design over the last decade, inspiring projects in my Zurich-based office DCT Architects, prompting theoretical writing and discourse, and influencing my teaching at various schools such as the Architectural Association in London, the Swiss Federal Institute of Technology [ETH] in Zurich, or the Institute for Experimental Architecture at the University of Innsbruck. Based on the formal pattern of interaction between the set of input \( \text{Para} \) and the set of output \( \text{Var} \), the design research can be differentiated into three types of investigation of increasing technical and conceptual complexity: the exploration of variation, of recursion, and of systemic interaction. [Fig 2]

**Variation**

In architectural design, the primary concerns must be with the arrangement of material in space, that is, the creation of spatial patterns of organisation. For this reason, geometric descriptions, and the use of geometric operations, are of major importance in any formal architectural methodology. In my design approach, my digital explorations are informed by a process of continual variation, which are in turn based upon the utilisation of a sequence of associated geometric operations. Such sequencing functions as a computable description \( p \) of a spatial pattern of organisation, and its application within the design process is twofold. On the one hand, the variation of the defining parameters \( \text{in} \in \text{Para} \) of the geometric relationship \( p \), alerts the adaptive spatial pattern to changing local conditions, much like the case of the U-shaped sections of the components in the Bifurcated Bridge. [Fig 3] In that project, the shape of the component – defined by a sequence of geometric operation – is constantly adapting to a given position along the boundary curves and the relative position between the focal points.

On the other hand, the continuous variation of input parameters results in a spectrum, \( \text{Var} \), of possible spatial patterns, facilitating an investigation into the architectural potential hidden within well-known typologies. Such an approach was utilized in the development of an urban masterplan for district 6 in Ho Chi Minh City. [Fig 4] Based upon proto-typical residential, mixed-use urban blocks and courtyard houses, two families of variations, with varying degrees of porosity and privacy, were developed. These families formed the primary building blocks for the urban proposal.

**Recursion**

In both of the above cases of variation, the complexity of the resulting spatial pattern of organisation is a direct consequence of the underlying sequence of geometric operations. In other words, the design is controlled immediately by the inherent logic of the function \( p \). The simplest method of overcoming this principal limitation of the formal design method, is to break the linear processing of the input \( \text{in} \in \text{Para} \) by feeding back the output \( \text{out} \in \text{Para} \) into
하중의 흐름을 연속 집결시켜써 상호작용으로 지물 안정화된 콘크리트 슬래브 디미를 구성하는 데 사용되었다.(Fig 7) 독일의 지붕 중축 디자인에서는, 제거 형식이 분산 형식과 결합해 단위 개체를 차별화하는 진화 과정이 되었다. 이것은 세 개의 원형형 기초 구조를 차합해 공간 전체 조건: 구조 필요 조건: 빛물 분배: 활용 툴과 통합적으로 고려할 수 있었다.(Fig 10)

체계적 상호작용

이와 같은 다양한 시세에서 건축적, 실용적 요건을 기술적 운영의 순서로 공식화되어 재구조가 반복될 때마다 변형없이 실행된다. 이러한 작용 원리는 다양한 요건 간 상호작용의 양식을 제한한다. 함수 p의 순환적 처리 과정을 더 일반적 형태, 즉 연속 가능한 함수의 체계적 네트워크(p, …, p,)로 분해하는 방법안이 상호작용의 더 복잡한 유형을 만들 수 있다.(Fig 2) 체계적 상호작용의 특정한 유형을 기반으로 해야 공간의 자기조직화(self-organization) 같은 현상을 건축 디자인 형상 탐색(form-finding)의 디지털 방법으로 연구할 수 있다.

체계적 상호작용은 오르레앙(Orléans) FRAC 센터의 설치물 벨자(Byga) 프로젝트에서 처음 모델링에 사용했다. 현재 디자인 디자인 접근법은 재료, 형태, 형태 디자인 과정에서 계속 반복해 통합하는 생성 체계(generative system)의 가능성을 풀어내고 있다. 그래서 나는 설치 디자인이 기지를 빛는 케이블 그룹에서 맥구조물의 배열이 갖는 상호작용을 탐구했다. 그것이 맥 모두 형태 적(competitive) 질력 시스템에 속하도록 상호작용의 발생 방법으로 만들어지고 최적화되고 보장될 수 있다. 조립을 수행하는 결과적인 의의를 상상해(Fig 11) 기지를 빛는 케이블 그룹은 60개의 맥 구조물을 공간에 적합적으로 분배하는 주요 시스템이다. 맥 크기, 곡률, 구조물 간 거리는 각 기자의 케이블 사이 거리가 결정된다. 시스템의 구조적 분화는 빛 반사와 그림자 유형의 경계에 직접 반영된다.

물자로 다자인된 벨리는 맥 구조물의 형상 양식에 기존 디자인 작업의 모형을 작용해 부분적 형상 탐색 과정을 간소화한다. 그러나 불질체의 상호작용은 아직까지 제대로 설명된 적이 없다. 그 이유로 연구 분야인 약한 협력 체계(weak collaborative systems)는 적은
the computable functions $p$, that is, to establish a recursion. [Fig 2] The feedback transforms the static relationship $p$ between $in$ and $out$ into a dynamic process of constant development.

In a recursive process, instated simple geometric operations can lead to spatial patterns of an unforeseen complexity. A good illustration of this phenomena is the design of Trace of History, an abstract sculpture that explores the limitations of the human perception of order, through the implementation of a simple combination of rotations and movements, operations that act as a foundation to the recursive process. [Fig 5]

Furthermore, recursions are potentially adaptive processes, due to the use of constant feedback that allows for adjustments in the development of spatial patterns. This phenomena was explored in more detail in an application for an experimental dance theater. [Fig 6] A ballet dancer was hooked up with a lightweight wireless physiological monitor for measuring and recording EEG, ECG, EMG, EOG, and PSG signals. The physiological measurements gave information about the current physical state of his body, and were converted into audio-visual depictions in real-time, permitting the dancer to perform a pas de deux with his own electronic representation as a counterpart. This way a recursive adaptation process could be established with the audio-visual representation as feedback for the dancer.

The architectural potential in the phenomenon of recursion – in both its complexity and adaptability – were explored further through a series of competition entries, using cellular automata as a recursive mechanism for a proliferation of performative patterns of organisation. A cellular automaton can be understood as a computational function $p$ that maps a sequence of binary values onto itself, i.e. $p: \{0,1\}^n \rightarrow \{0,1\}^n$ with $N$ the number of cells in the system. In most design applications, cellular automata are used as simple discrete models for pattern formation based on regular grids, e.g. in the study of interacting cell systems in biology and medicine, or in the simulation of urban growth strategies. In the competition entries, however, the function $p$ was not used to organise a spatial pattern but rather to assign a binary value to each cell as a flag in a continuously repeated quality check. Because of this, using similar rules to John Conway's famous Game of Life, the cellular automaton was able to correlate the fitness tests of neighbouring cells, resulting in growing clusters of performative neighbourhoods.

Whilst designing a high-rise block, this strategy was applied to a number of components as building blocks in order to develop a façade that became an exterior structural system, functioning at the same time as a fractal sun-shade. [Fig 7] In a second competition entry for an orchid grower's greenhouse, the cellular automaton was used to organise a differentiated roof space in such a way so the rain water was moved to specific points on the surface. The necessary amount of energy required to heat the covered space could be harvested by integrated sun collectors. [Fig 8] For the design of a visitor's center in the Slovenian mountain region, the cellular automaton approach was used a third time, in order to organise a self-stabilizing pile of enmeshed concrete slabs, by successively...
적재응용을 가진 물질 요소를 집성해 인접 요소와 싱크작용함으로써 큰 규모의 안정적인 공간을 구성하는 과정을 이해하는 것이다. 이러한 행동은 상용적인 것으로, 여러 절은 목재 구조가 직조 방식으로 노선하게 연결된 구조적 시스템으로 하중을 인접한 여러 개의 구성 요소로 분배할 수 있다(Fig 12) 세를 등급 같은 자연의 건축물의 콘크리트(discrete elements) 구조적 시스템 사례다. 휘어(bending)의 접시(folding) 같은 기하학적 공정을 통해 다양한 디자인 스타일이 연구하고 있는 다른 사례도 있다. 이러한 공정을 통해 국부적인 강성도(stiffness)가 증가하고 다른 부품과 연결되기 때문이다.(Fig 13)

위의 연구에서 전체 형상은 구성 요소의 국부적 상호작용에 의해 만들어진다. 체계적 행동 양상의 디지털 모델링은 연산 가능한 함수(p, ..., p)의 집합을 사용해, 결과의 형태의 발전 과정을 상세하게 연구할 수 있게 된다. 함수 p 중 하나를 수정해 구성 요소들 국부적으로 증가함으로써 형태의 발전을 통제하는 연구도 가능해졌다.

질료 형성 구조학(Hylomorphic Tectonics)

전통적으로 건축과 디자인을 성형하는 데 사용하는 디지털 기술에 대한 논문은 이제 논문보다 우위에 있다. 재료는 주로 형태를 위한 미적 특성이나 기술 성능 연계에서 다루어진다. 재료의 물성이 현재 디지털 기술이나 물리적 형상 합성 기술 과정에서 주요한 역할을 하지는 못한다. 재료의 형상을 기술하고 설계하는 데 부수적 수단일 뿐이다. 나는 디자인 초기 과정부터 구조를 통합적으로 고려하기 위해, 힘의 효율의 논리를 이해하는 것과 디지털 도구를 발전시키는 것을 연구 중이다. 이는 토목 역학(graphic statics), 즉 형태와 힘의 상호 모수적 관계를 기반으로 한 지지 구조의 힘의 효율을 백터 기하학으로 표현하는 것을 중심으로 한다.(Fig 14) 그러므로 토목 역학은 형태와 지지 용량(load-bearing capacity)을 통합적으로 이해할 수 있게 한다. 지지 구조에 적용하는 힘의 형태적 효과와 목표형 제어(targeted control)를 이해하는 것이다.

생물, 무생물은 포함한 모든 물리적 존재는 중력, 풍압, 대기압 등 주의 환경에 및하는 다양한 형에 대응해 자연물질성을 유지해야 한다. 설계적으로, 물리적 존재의 물성은 단계의 고품질 동시적 원칙, 즉 주요 몰입 시기에 공간을 형성하는 구조다. 두 개 원칙이 위업한 물리적 세계에서 하나는 다른 하나 없이는 발생할 수 없다. 형태 없이 물질도 없고, 물질화 없이 형태도 있을 수 없다. 비록 형상
building up load paths along touching slabs. [Fig 9] For the design of a roof extension in Germany, the formal method of recursion was also combined with the method of variation, resulting in an evolving process of cellular differentiation, enabling the combination of spatial prerequisites, structural requirements, rain water distribution and sun-light penetration through the permutation of three conical building blocks. [Fig 10]

Systemic Interaction

In all of these different applications, the architectural and performative requirements are formalised into a sequence of geometric operations, unerringly executed in each iteration of the recursion. Due to this mechanism, the pattern of interaction between the various requirements is limited. Only by breaking up the cyclic processing of the function \( p \) into a more general form of recursion – into a systemic network of computable functions \( \{ p_1, \ldots, p_n \} \) – can a more complex pattern of interaction be achieved. [Fig 2] It is only within this more complex pattern of systemic interaction that phenomena like spatial self-organization can be explored as a digital method of form-finding for architectural design. The first digital attempts made at the level of systemic interaction modelling were made with respect to the installation Bygga at the FRAC Centre in Orléans. Contemporary digital design approaches have not yet taken full advantage of the possibilities offered by such a generative system, one which integrates material, form, and force as continuous iterations in the design process. That is why the design of the installation is exploring the interaction amongst arrays of membranes set within a branching cable-net. Both net and membrane belong to form-active tension systems and can thus be form-found and optimised together, calibrated in an interdependent way. The assembly displays hierarchical articulation as a result of the form-finding process. [Fig 11] The branching cable-net is the primary system that serves to distribute sixty membranes strategically in space. Size, curvature, and distance of the membranes are determined by the distance of cables in each branch. The hierarchical differentiation of the system makes it possible to yield equally differentiated effects, most particularly with regards to light reflection and shadow patterning. In the case of the Bygga, the form-finding for the parts of the installation was simplified due to the pre-existing digital relaxation models detailing the behaviours of the membranes. In general, however, descriptions observing the interplay of such material systems does not exist. Because of this, one of the major fields of research in which I am involved is the study of weak collaborative systems, attempting to understand the process of aggregation between material components with a low-load capacity into larger stable spatial organisations, caused by the interaction of neighbouring components. An example of such behaviour is in reciprocal frames, i.e. structural systems formed by a number of short bars that are loosely connected in a weave-like manner, enabling distribution of loads into the differing neighbouring components. [Fig 12] Comparable structural systems comprised of discrete elements do occur in Nature, for example in animal architecture such as bird nests. Other examples have been explored in a number of design studios, using geometric operations like bending or folding. These operations help to increase stiffness locally and enable linking to other components. [Fig 13] In all of these studies, form is the result of local interactions between constituent components and the digital modeling of systemic behaviour, using a set of computable functions \( \{ p_1, \ldots, p_n \} \) This makes it possible to investigate in more detail the development of the resultant form, and how to control it through local interventions at the elemental level of the components, through modification of one of the functions \( p \).

Hylomorphic Tectonics

Traditionally, the discourses within architecture, and the digital techniques of design practice, have privileged form over material, with material rarely examined beyond its aesthetic properties or its technological capacities to act as a servant to form. Neither in contemporary digital nor in physical form-finding techniques do material properties play a major defining role in the process; material is merely a subordinate means of tracing the form and making it buildable. Because of this, part of my more recent research activity has been focused on acquiring a better understanding of the logic of force-flow, as well as on the development of digital tools in order to integrate structural considerations into the design process in the earlier stages. My research centres on and around the method of graphic statics, a vector-geometric representation of the force-flow in supportive structures that are based upon the reciprocal parametric relationship between form and force-flow. [Fig 14] Thus, graphic statics encourage a unified understanding of the interplay of form and load-bearing capacity – that is, an understanding of the formative effect of active forces within a supporting structure and the targeted control of these forces.

Every physical being, living and non-living, has to support its materiality against the various environmental forces that are imposed upon it, such as gravity, wind or atmospheric pressure. Philosophically speaking, the materiality of physical beings can be thought of as embodiment of two intrinsic coincident principles: matter, and its form, its gestalt in space. Both principles are intricately interwoven, and in the physical world one cannot occur without the other; no material is without form and no one form exists without materialization. The question of form in architecture cannot be treated independently of matter, even when the strongest architectural interest is in form-finding. It is material through which forces flow, and the arrangement of material in space – the pattern of its distribution – directly influences the efficiency of the flow of forces, the direction of the flow, and its resultant intensity.

This design approach, balancing material, form, and force, has been tested in a recent series of new build projects, such as in the temporary light timber construction that functions as a sun awning over sections of the grand stairs of the architecture department of the ETH. [Fig 15] It is based upon bending behaviours under the self-weight of oversized sheets of plywood of up to 11 x 2.5 m. The design activates the material properties as the defining element in the transfer of forces. Using graphic statics, a digital model of the interplay of material, form, and forces was developed, and later compared and calibrated with the build project. The exploration of the sheet material and the manipulation of its bending properties, in controlling the number of layers of ply and the direction of the fibres within these layers, formed the starting point of the design process. The precise geometry of the bending curve emerged out of a consideration of the distribution of matter, the hierarchy within plywood as composite material, and given load conditions. Based on a systematic investigation into the defining parameters, sheets of 118 mm thickness, with fibres mainly in longitudinal direction, have been used for the pavilion. Cuts within the sheets influence the bending resistance of the sheets, enabling a larger spatial enclosure and a reduced wind-load acting upon the structure, which additionally produces a shadow pattern, flooding the stairs that are also used as seating area during summer time.
정부의 경제·사회·문화와 사라지지 않는 원리가 있다. 정부의 경제·사회·문화와 사라지지 않는 원리가 있다.

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Fig 16. ETH/AA-Pavilion
Simple construction of pavilion through bending

Cuts within the sheets influence the bending resistance of the sheets
자료 등이 있다.**

내재된 연산 가능한 함수를 인지해 디지털 디자인과 디지털이 아닌 디자인을 구분한다. 형식적 원칙을 통해 건축의 디자인 방법을 확장한다. 동시에 컴퓨터를 재료의 품성에 대해 전통적·현실적 해석과 다른 새로운 이해, 유물론적 관점을 "우리가 생각하는 방식을 바꾸는..."적 학용"으로 디자인 경제에 도입한다.

컴퓨터를 통해 건축적 사고를 재정립하는 것은 물리학 생물학 같은 과학 분야의 변호에 필적할 만한 폐쇄의 전환이라고 생각한다. 1960년대부터 자연적 과정의 시뮬레이션과 모델링의 주요 도구로 컴퓨터를 도입하면서 자세적인 연구를 탐구한 결과 추가적 관점은 계속 수정되거나 대체되었다. (Fig 19) 즉 자연에 대한 기계적 이하와 전통에서 부분으로 집합되는 하향식(top-down) 방법은 교제되었다. 국가적 계획을 유형에서 전반적 시스템의 상향식(bottom-up) 특성으로서 부분의 포괄적 범위로 전환된 것이다.

컴퓨터와 소프트웨어가 새로운 구성 방법과 형태 생성 방법을 생산했기에, 건축가가 자연의 시스템적 모델에 흉미를 가지는 것은 당연해 보인다. 그 결과 지난 수십 년간 과학에서 얻은 체계적 개념은 건축 담론으로 확산되었고 현재는 디자인을 위해 연구되고 있다. 이것이 연구의 발언이다.
Varying the length of the sheets generates small variations in the bending curve, utilized for the overlapping and interlocking of adjacent elements, resulting in a system of self-stabilizing vaults. The vaults are cross-braced by a sequence of cables. These cables distribute all other load conditions evenly within the edge strips, and so minimize the possible deformation of the arched form.

**Fabrication**

One of the most important aspects of the pavilion design was the ability to pay real attention to material behavior, not only in the process of form-finding but also to take advantage of such material manipulation within the construction of the building. Due to the flexibility of the pig sheets, no machines were necessary in the assembly; simply through sheer man-power the sheet could be bent and lifted into place. (Fig. 16) This meant that the design process could be freed-up from potential limitations caused in fabrication. In general, the fabrication and the assembly process has to be seen as a knotting together of all the material considerations that influence the design, i.e. as the parametric input into a computable function within the set of functions {p_i, ..., p_n} of the network of systemic interaction.

In designing an experimental structure out of steel pipes, even the limitations of the bending machine were instrumental, guiding the design. (Fig. 17) While pipes can be bent with a variety of techniques, most CNC bending machines use the method of rotary draw bending. This, however, causes a number of restrictions: the minimum radius depends on the diameter and the quality of the tube. The bending angle must not be greater than 180 degrees, to get the tube off the machine. The minimum straight required between bends is equal to the clamp length. The last straight piece of the tube also has a certain minimum length, so the pressure may stabilize the final bending.

The bending machine used had an electronically, CNC controlled, forward drive (L), rotation axis (R), and bending axis (A). So far, however, the software controlling the bending machines has no interface for importing CAD data directly. The geometry of the polyline, that defines the desired shape, had to be inserted manually rather than in XYZ or LRA coordinates. Consequently, the geometric setting of the machine had an immediate influence on the geometry of the design, and had to be worked into the network of relationships {p_i, ..., p_n}.

Additional modifications, such as the economic division of the polylines and the consideration of the connections, were integrated into the network, adding further restrictions to the design.

**Conclusion**

My work — in projects, research, and in teaching — is centered around the question of computability, in the production of causal relationships between quantifiable entities, and the construction of geometric logics. (Fig. 18) The use of the digital formalizes architectural thinking, but this shift towards the formal does not mean a loss of design freedom. On the contrary, it allows for new forms of creative expression because “computation is about the exploration of indeterminate, vague, unclear, and often ill-defined processes; because of its exploratory nature, computation aims at emulating or extending the human intellect. It is about rationalization, reasoning, logic, algorithm, deduction, induction, extrapolation, exploration, and estimation. In its manifold implications, it involves problem solving, mental structures, cognition, simulation, and rule-based intelligence, to name a few.”

Thus, an awareness of the underlying computational function marks the threshold between non-digital and digital design, defining an extension of design methods in architecture through this exploration of formal principles. At the same time, computability facilitates a new understanding of materiality, that differs from the traditional phenomenological reading of material in architecture, introducing a materialistic view into the design process as part of the “intellectual revolution…” [that] is changing the way we think.

By means of computation, a reshaping of architectural thinking has to be seen as a paradigmatic shift comparable to progressive changes in sciences like Physics or Biology. Since the 1950s, the introduction of the computer as the primary tool for simulating and modeling natural processes has resulted in a successive modification or even replacement of reductionism, as the predominant paradigm of research. (Fig. 19) As such, the mechanistic understanding of nature, and the continuous top-down reduction of the whole into parts, has been transferred from patterns of local interaction into an overall global arrangement of the parts, as an emergent bottom-up property characterising the overall system. It is not surprising that architects became interested in these systemic models of nature, influenced by the related new methods of organisation and form-generation provided by computers and the appropriate software. As a result, over the past decade, systemic notions and concepts from science have diffused into architectural discourse, and are currently explored for design purposes. It is at this very point that my work is situated.

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Toji Kottuk is assistant professor at the Institute for Experimental Architecture at the University of Innsbruck and lecturer at the chair of structural design at the ETH Zurich. He studied architecture and mathematics at ETH Zurich, CH, the University of Tübingen, G, and the University of Utah, USA, and received his doctoral degree from the University of Zurich, CH. He was research fellow at Center for the Representation of Multi-Dimensional Information [CRMDI], principal researcher at OCEAN design research network, postdoctoral researcher at the ETH Zurich, adjunct assistant professor at the University of Applied Sciences in Lucerne, CH, and studio master at the Emergent Technology and Design program at the Architectural Association in London, UK. His practice and research work has been published internationally and is centered on the integration of scientific knowledge into the design process with focus on the relationship between digital architectural design, geometry and material behaviour.