Printing Out Buildings
Code—Printer—Buildings

Oliver Fritz

Since the beginning of the 20th century, architects have been experimenting with industrial methods of construction to build residential housing. Experimental projects like Gropius' Dessau-Törten as well as constructive experiments by Wachsmann and Prouvé provided the basic insights that led to prefabrication as practiced in the construction industry today. The various design and production methods that have resulted from this effort encompass a broad spectrum ranging from prefab homes—uniform and ready for occupancy—to highly developed modular construction systems, all the way to façade elements that are prefabricated in the workshop and installed in a large-scale application process on site. These systems assume fundamentally different forms but display a number of shared characteristics and objectives: shorter time spent on the building site, higher degree of precision, increased security, and reduced costs of planning and construction. Conventional prefabricated housing construction is extremely limited and practically no customizing by either the client or the architect is possible, while modular construction systems are distinguished by their regularities and uniform patterns. Building elements individually prefabricated in the workshop are generally not restricted to a predetermined form or mode of installation.
On the other hand, construction costs are usually proportional to the flexibility of the construction method. As a rule, traditional and less flexible planning and construction methods are more economical. A real challenge for the future of industrial construction is to enable builders to react to clients' individual wishes and needs. In the industry, there is an increasingly widespread orientation on individually customized mass-produced structures. In the past, this was practiced only in cases of cost-intensive products (like those of the auto industry) available with limited configuration options; now, there are firms that are customizing small, lower-priced products. This tendency is being made possible, above all, by new types of information technology, new forms of communication (like the Internet), as well as modern, individualized fabrication techniques.

http://eu.cmax.com/
Customized Footwear

For the last two years or so, the Department of Computer Aided Architectural Design (CAAD) at the Swiss Federal Institute of Technology in Zurich (ETHZ) under the direction of Prof. Ludger Hovestadt has been conducting research on the integration of state-of-the-art information technologies into architectural production and design processes. The aim of this research is neither the formal development of a new type of architecture nor the definition of stylistic or formal characteristics; rather, the point here is the structural development of buildings in a way that proceeds from their essential "core" and the formulation of this process in a unified code that no longer provides an exact rendering describing a piece of architecture but rather fixes it as a program in a set of data—as what might be termed a "genetic code" that contains all relevant information about a building but no prescribed form of representation. This set of data can be configured, displayed or produced by any output device: in the Internet, via plotter, or directly as a structural component.

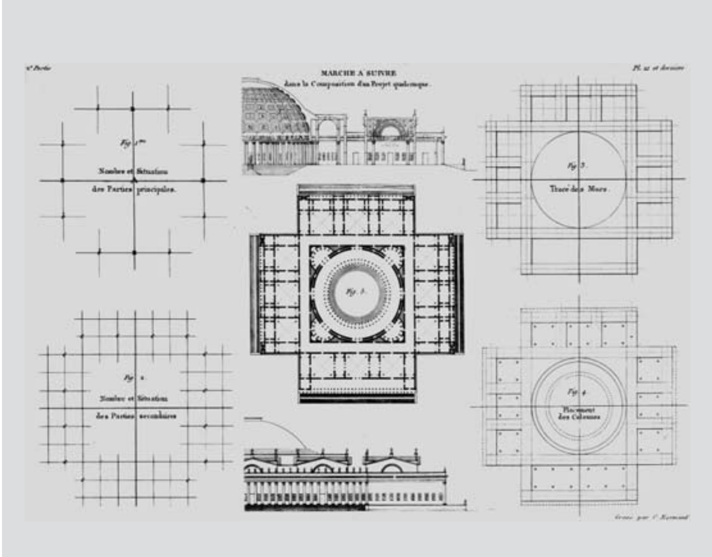
Programmed Architecture

Previous attempts to program software to generate architecture to some extent independently have run up against a very generalized problem in the field of architectural design: objectifiability. To what extent can the solutions generated in this way be objectively assessed? Issues of a functional nature—such as keeping distances that users have to walk within the building as short as possible—can indeed be analyzed adequately, but not the question of whether the windows on a particular façade ought to be rectangular or square. The problem that usually arises in evaluating architecture is that there frequently is no clearly "right" or "wrong" solution, but rather only one that someone likes or not. The assessment cannot always be supported with objective criteria; subjective taste is often the determining factor. Efforts to equip programs with learning algorithms—akin to genetic algorithms or neuronal networks—have not been an unqualified success thus far. Obviously, the interrelationships among aspects like physical setting, analysis, idea, style, space utilization program and choice of materials are too complicated to be succinctly summarized. And every designer has a different conception of the hierarchy and the importance of the individual aspects. Similar problems arise in the field of computer-generated music with the attempt to simulate classical composers, whereas new compositions not subject to these restrictions can be programmed very easily. Accordingly, there can be no generally applicable software or universal machine to design architecture.

How, then, could the computer—as a tool with great promise for the future, and beckoning areas of deployment that go beyond the electronic drawing machine, communications manager and archiving system—serve as a means to support the design process, and what consequences would such use have for architecture?

One of the first "programs to generate architecture" was described by Jean Nicholas Louis Durand in his 1819 book *Marche à suivre. Précis des Leçons d'Architecture données à l'Ecole Royale Polytechnique.* In it, Durand derived the construction of a detailed building from a few simple, multi-step rules. He formulated the axes of reflection and the minutest commonalities in his program and, in this way, unmistakably described the architecture. The result with which we are confronted is a plan in which, for one thing, elements are arranged in a way that is by no means haphazard and, for another, it is very easy to discover errors. This is not a program that generates architecture; rather, this is a case of programmed design—a description of a building that could not be more compact and one that avoids redundancies.

As far as the description of objects is concerned, modern object-oriented programming languages have a crucial advantage over Durand's linear (procedural) descriptions. With



From: J. N. L. Durand,
Marche à suivre

them, exceptions as well as rules are described in such a way that characteristics of a precursory object can be overwritten. In this way, it is relatively easy to build up very compact and yet highly adaptable structures that can be used both descriptively and operationally. This mode of programming is most convenient for the task of architectural design since structures can be described in detail without a definite solution to a superordinate problem having to be found.

Laser Printers and CNC Machines, Programmed Objects and Postprocessors

Only a few years ago, producing a single copy of a book, for instance, or a limited number of color postcards was a rather highly involved undertaking, since such jobs only made economic sense with print runs over 1,000 copies. Approximately 10 years ago, the first color laser and inkjet printers came onto the market. A laser printer was a considerable advance over its forerunners such as offset printing machinery. With this new technology, it makes no difference whether one prints out a single copy or multiple copies of a page. A new typeface or a completely different layout can be selected for every page. The laser printer is a flexible output device for any content whatsoever, whereas offset printing machinery is set up to turn out a single page at a time. These functions can also be usefully applied in architectural production processes, assuming compatibility between the descriptive format and the output device is achieved.

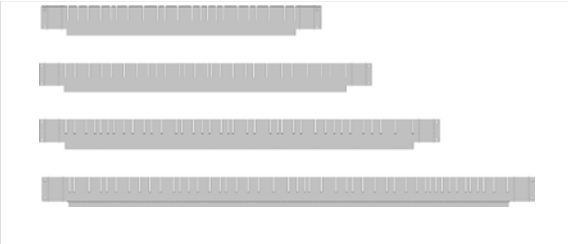
As previously mentioned, architecture can now also be designed as a program instead of, as is usually the case, as a blueprint. The essential innovation here as far as architecture is concerned is the ability to take the code that describes a building and, through the use of so-called postprocessors, to generate a variety of different forms of representation: a CAD rendering, a print file, a data sheet featuring a list of components, or an invitation for tender offers. In most cases, postprocessors are small translation programs that produce the necessary data from the code.

If the programmed architectural object offers a “print” option and if the program can execute it, a CAD rendering is generated from the code and sent to a laser printer. The printer, in turn, carries out this program in step-by-step fashion and produces a drawing of the programmed object on paper. In doing so, it makes no difference to the laser printer which printing instructions have been sent by which object, just as long as it is able to execute the program. Furthermore, the above-mentioned program can also feature a production

digitales bauen, Volkmar Hovestadt
The graphic shows a 30-meter-long machine for molding wood
CAAD.ETHZ.CH

Cutting head of a laser cutting machine
plate size: 3 x 1.5 meters, plate thickness: up to 1 centimeter

option, whereby the necessary production data are calculated from the code and sent to the corresponding production machinery.
Thus, if the laser printer as a machine is capable of printing onto paper, it follows that there must also be computer-controlled machinery capable of directly “printing” a construction. With respect to technique and content, the problem of “printing out buildings” seems to have been solved. Just as a programmed object can be printed to paper with a laser printer, the same object can now be “printed out” in concrete with a concrete plotter. Metals and plastics can be cut with laser cutting machines; any imaginable form can be produced from glass or stone with water-jet cutting machines; plastics and wood can be worked with computerized numerical control (CNC) molding machines.
In accordance with this line of thinking, a current challenge for the field of architecture is to develop and implement structures that are compatible with these principles and can be produced on such machinery.
Here is brief but easily understood example meant to clarify the idea of a parametrized object and the series of steps involved in producing one. A rack for hanging up clothing is described in a program; entering the corresponding parameters—e.g. its length or the minimum distance between the individual notches that anchor the hooks of whatever sort of clothes hangers are used with it—makes it possible to generate a specific object that can be produced directly by means of a laser cutting device. Whether three of the same objects or three different ones are to be produced does not have a material effect upon their price: a rack costs about 100 Swiss Francs per linear meter. This is a programmed design from which, in a matter of seconds, an unlimited number of different objects can be produced.



Parametrized Objects
Design: Christoph Schindler, CAAD ETHZ

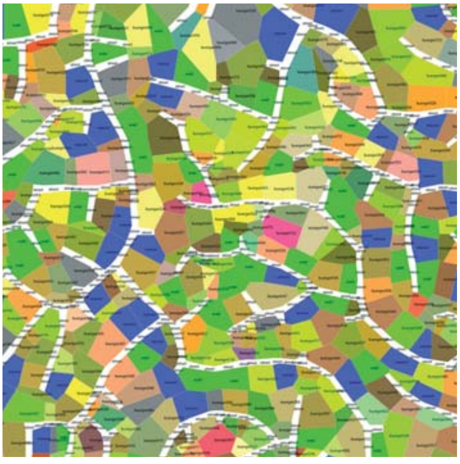
From this, it follows that the economic viability of a piece of architecture is no longer proportional to its uniformity. If a design consists of many different objects of the same type and it can be described and designed in this way, then this has far-reaching consequences for the organization, construction and design of architecture.

Prototype = Series

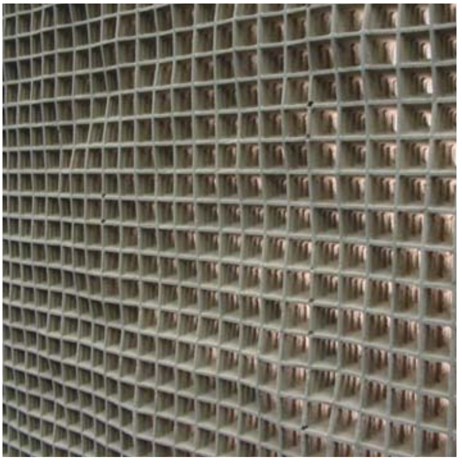
When CNC machinery is used, the production costs of a prototype differ only slightly from the costs of producing a component in serial production (assuming that the concept of serial fabrication still even plays a role in this type of development and production process). With these design and production principles in force, very small production runs can be economically set up, produced and marketed with the use of very limited personnel resources. From the architect's point of view, the blending of a form of organization derived from the crafts and trades with industrial production methods could open up attractive new possibilities. After all, why shouldn't he go ahead and create a prototype of the façade component he developed himself, and, ultimately, produce it himself too?
According to the principles of conventional industrial construction, the development of a building component means a high initial investment which can only be amortized through big production runs, an elaborate marketing campaign and a large working group; here, however, it is conceivable to generate constructions and details that are highly individually adapted to a particular piece of architecture.

Summary / Work in Progress

Works of architecture can be programmed both generatively as well as descriptively and in a way that is economically viable. By way of illustration, I present several projects with which I have been associated—one involving the firm *digitales bauen* and the collaborative project entitled *"KaisersRot"* carried out by the ETHZ and the Dutch architectural firm KCAP Rotterdam.

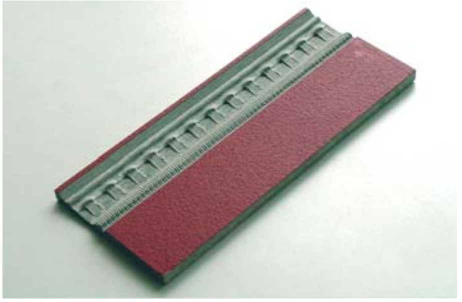


"KaisersRot." A collaborative project of KCAP Rotterdam and ETHZ. A computer-generated lot layout plan. Software: Markus Braach, ETHZ



Façade element. Work by student Matthias Heberie in the course "Surface Light," Russell Loveridge, CAAD ETHZ. The image hidden within the structure becomes visible under different lighting conditions.

Milled Eternit plate
Christoph Schindler and Russell Loveridge, CAAD ETHZ.



Perforated bend detail, CAAD booklet rack
Oliver Fritz, CAAD ETHZ

Structures are generated and described in both examples, and this is done more economically and more efficiently than with conventional methods. Projects like the clothes rack or the NDS Pavilion, in which the generated code—uniform for the design itself and the drawings of it—is also carried over into the CAM process, show how the future of an integrated design, description and production process for architecture might look.
Accomplishing this, however, will necessitate gaining additional experience with a wide range of “printing technologies.” For example, a new printer driver for the concrete plotter will be written in the coming months, which will make it possible to produce walls directly from CAD programs or from the code.
Aside from the technical issues involved, these production processes also exert a not inconsiderable influence upon the design of architecture. For example, what might the details and exterior surfaces of computer-programmed and computer-produced architectural works look like? Could this possibly give rise to a new type of ornamentation?
The range of possibilities discussed above opens up a great deal of room for new experiments of a technical and formal nature. The decisive aspect of this effort will be to pragmatically pursue the objective of “printing out buildings” and its consequences for architecture in a manner that is free from ulterior motives of an esoteric nature.
After all, in the past, changes in construction technology usually manifested themselves very directly in the design of architecture.

Translated from the German by Mel Greenwald

NDS Pavilion 2001 / 2002, CAAD ETHZ.
Seven postgraduate students are designing and building a structure consisting of 418 different parametrized and programmed components.