Automate Architecture

Alfredo Andia
Florida International University

AUTOMATING DESIGN

The possibilities of automating design have grown quickly as architects and engineers have begun to use parametric software in the past decade. The most basic conceptualization of parametric refers to a 3D digital model associated to knowledge structures, information, performance properties, and automatic procedures that can aid the designer to construct quick scenarios during design. These models can be updated overtime and reused. They can further breed its associations to all kinds of data, performance parameters, procedures, and knowledge. As more parameters are included, the design process can become increasingly aided by algorithms creating a design-assisted environment similar to the one electronic chip designers use to devise, analyze, and verify printed circuit boards and integrated circuits.

Brief History of Parametric

Parametric is not new. Parametric ideas in design modeling were an essential feature of the first CAD program, "Sketchpad," developed by Ivan Sutherland in 1962 and also part of the pioneering CAD systems in the early 1970s such as SSHA, CEDAR, HARNESS and OXSYS. These CAD systems had particular parametric features that were associated to a particular type of knowledge base to serve particular organizations and building types (Mitchell 1990). OXSYS was the precursor of BDS (Building Design System) and RUCAPS (Really Usable Computer-Aided Production System), which became available commercially in the UK in the 1970s and surfaced with concepts very similar to today's BIM systems.

All these systems had a common vision: to construct virtually a 3D building by modeling all their building elements and assemblies. They allowed multi-users to manipulate a single parametric 3D model in which graphic reports and 2D drawings were mere automatic derivatives created from the main 3D model. By the mid-1980s a second wave of 3D parametrically based software such as SONATA, Reflex, CHEOPS, GDS, CATIA, GE/CALMA, and Pro/Engineer achieved commercial presence. SONATA was the direct descendant from the RUCAPS software of the 1970s and engineers from SONATA created the company that launched the software REVIT which was later acquired by Autodesk.

Many of these pioneering parametric programs in the 1980s, became standard in industries such as electronics, infrastructures, aerospace, and car manufacturing. However, most practices in the architecture, engineering and construction (AEC) industry preferred to implement 2D CAD systems in personal computers. It took close to two decades for the 3D parametric model to make a significant comeback in the AEC industry.

FOUR PARAMETRIC PARADIGMS

As 3D parametric software and tools are being rediscovered by architectural firms, the former are beginning to change design workflows. We think at this moment contemporary design practices have developed at least four different narratives with regards to parametric design.

Parametric Formalism: The Digital Avant-Garde

Parametric modeling and scripting has been used to find intricate utopian/dystopian formal visions in studios usually led by professors that are closely linked to the paperless studio digital avant-garde that emerged in the 1990s and 2000s. Architects using this narrative use parametric techniques to substitute the sculptural or figurative designer in developing complex spatial formation.

In the past few years Patrik Schumacher, partner at Zaha Hadid's office, and head of the "parametric urbanism" program at the Architectural Association in London has acquired a leading voice. Schumacher argues that there has been a solid trend in the architectural avant-garde in the past 15 years in rooting their processes in digital animation technique. He observes that it is impossible to compete in the avant-garde scene today without using computational techniques, such as scripting and parametric modeling. He goes further to argue that: "Avant-garde styles can be interpreted and evaluated analogously to new scientific paradigms," making a clear call for opening that traditionally closed black box that has traditionally permeated the avant-garde design culture (Schumacher 2009).

Schumacher calls "parametricism" a style. He, as most digital avant-garde designers, is developing these techniques to differentiate his work in a design environment infatuated with shape generation possibilities. Families of forms and software tricks such as the vornoi scripts bounce in blogs across the oceans and between architectural schools. It has become difficult to distinguish their authors. Suspending any aesthetic judgment, these innocent free-scripting libraries are some of the first sign that architectural design, in this case geometric complexity, can began to get disengaged of individual authorship, coded, an re-applied to other projects by potentially other authors.

Parametric BIM

BIM has become one of the central themes in the computerization of architectural practice today. BIM software and processes allow architects to construct virtual models that accurately replicate building systems and materials. The parametric model is linked to a database that contains information such as construction estimates, schedules, fabrication details, and construction simulation. Any change in the 3D model automatically updates the database and other construction documents such as 2D plans, door schedules, and specifications. The basic premise is that by building the facility virtually in 3D, one can test the potential problems during construction and simulate alternatives.

BIM narratives in practice have mostly concentrated in what the AEC industry calls 3D, 4D, 5D, and 6D BIM: 3D BIM refers to collision detection models; 4D BIM are coordinated construction sequence models; 5D BIM are models associated to budget and cost estimation; and 6D BIM are models used for facilities management during the life span of the building. The merging of these parametric BIM models with embedded sensors-procurement procedures, intelligent 3D libraries, price engines, and bidding systems will move the narrative further. However, despite the exaggerated claims that BIM is "revolutionizing" AEC processes, BIM is still very manually intensive, and it is not a significantly more intelligent method. The contemporary discourse of BIM that is being sold today, more than creating a true "revolution," is just modernizing an AEC industry that in the US has progressively abandoned the design-bid-build delivery method and moved into a design-build world in just two decades.

Meta-heuristic Parametric

A third type of narrative about parametric design is beginning to emerge in research and development (R&D) units inside large firms. Many of these units are developing generative procedures that can integrate certain design workflows with interactive modeling tools and procedures. The R&D group inside Aedas Architecture is one of those examples. The group is project-driven, it works by aiding the firm's architects to explore generative and analytical computational processes in design.

The group has worked in a variety of projects: from façade systems, performance analysis, digital layout, to large urban design proposals. The objective is to develop methods for design that explore the spatial and performative conditions of design more than just specific geometrical solutions for a project. Their work is closely related to academic ambitions explored in schools such as at the University of East London, University of Central London and led by, among others, Paul Coates (Coates 2010).

In developing their tools and processes the group has developed meta-heuristic techniques to augment the traditional rules of thumb used by the design teams in the firm. In computer science, meta-heuristic is a computational method that searches for a large number of candidate solutions. Meta-heuristic is an iterative process that can search quickly a large number of candidate solutions, but that cannot assure that an optimal solution can ever be found. Among the many computational methods that they have developed are the following.

Adjacencies and layout: The Computational Design team has developed several 3D tools to help designers understand adjacencies diagrams and program layouts. These tools are semi-automatic, not fixed, and the user can move bubbles and volumetric rooms while the adjacencies among functions are maintained. As the user moves the volumetric rooms, they behave like 3D Jell-O boxes that attract or repel different configurations based on their topological configuration. These tools are intended to intensify the reflective period design teams have with the program layouts rather than provide fully optimized solutions (Derix 2010).

Digital master planning tools: The Computational Design Team at Aedas also has developed parametric methods such as massing, accessibility and movement, strategic planning, investment appraisals, and others that have been implemented at the urban scale. Two critical issues have emerged in the creation of these digitally assisted methods. The first is that users always continue to ask for more features to be added to the computer model. This creates a major visualization problem because these systems can became overwhelmed with information and the clarity and simplicity of the information can easily be lost. The second theme emerges with the potential temptation to develop optimization procedures. These systems are developed using a multi-criteria development and often there is no clear way to offer a family of optimized solutions. So an option is for the methodology not to provide any solutions and focus in usability and engagement criteria with the user.

The observations in usability became important, as it is usually critical to understand the type of supervision these tool requires. Sometimes computers run too fast, and it is better for the user to see how it struggles for a solution. At that moment the users can see potential candidate solutions and by accident help move along different scenarios in the discussions that accompany a typical planning process.

Parametric Topology

A fourth narrative in using parametric techniques is guiding designers into coding design thinking. This means the development of computing frameworks that associate 3D models with other parametric factors such as: land cost, density, codes, regulations, structural parameters, acoustics, automated layouts, sunlight, climatic evaluations, etc. We are not talking here about generic software, but scripts that are tailored to precise design thinking related to a particular architectural program, site, and cultural context. The architect in this milieu becomes a topological operator and the 3D design model turns into a dynamic mock-up model full of parallel intelligent scaffolds that can quickly test multiple scenarios.

Perhaps the most remarkable prototypes of coding design intelligence can be found in the “Associative Design” Studios led by Professor Peter Trummer at the Berlage Institute in the Netherlands. In essence, the studio uses software devised for the manufacturing industry and adapts it to generate complex parametric models for a large housing project in China. The year-long studio project is a large mass housing and urban development for around 8,000 people in the outskirts of Shanghai.

Today, most mass housing solutions in China are large mid- to high-rise building blocks that repeat ad nauseam because it is very difficult for architects and developers to conceptualize the problem in a different manner given the time and constructability constrains. China is urbanizing 500 million people in a decade and contemporary architecture is too slow. Thus, most contemporary architecture in Chinese cities has been defaulted to a copy and paste mode. Copy and paste communities create generic and segregated communities that are far away from the way the traditional vernacular Chinese cities performed.

The main question of Trummer's studio was: How can architecture learn from the Chinese traditional non-planned settlements? The first part of the studio studied the different type of non-planned settlements. The studio observed the social organization of housing and its relationship with landscape, water, and materials. The studio studied details such as wood sizes or the curvature of tiles and analyzed particular themes such the degrees of intimacies that different types of programs produce in traditional Chinese architecture. They studied different types of regional typologies across China. These studies came to one conclusion. That the Chinese vernacular is dependent on two conditions: (1) climatic performance, and (2) social organization. Then they tried to code this. The class was divided in groups of two students. Each group was in charge of developing a parametric environment that contained the topological observations they made about non-planned settlement and applying it

The studio was also divided into research teams that studied issues such FAR, circulation, internal room organization, land-value strategies, sun trajectories, parking requirements, Chinese national code, traditional construction techniques, and the traditional vernacular Chinese housing. The studio discovered that each one of the issues studied had a clear morphogenetic intelligence. These observations were coded into the manufacturing software achieving parametric and associative values.

The self-generative 3D routine automatically develops the internal layout of each apartment. For example, when the perimeter of the housing project has to change, the software interactively updates the design of the entire apartment, including windows and egress following the coded criteria. The routine calculates the spaces based on the studies of traditional use of courtyard, population densities, family structures, circulation requirements, egress, national sunlight and ventilation regulations, and different configuration for diverse income groups.

The associative model allows the designer to consider many domains that are impossible to consider in a manual drawing process or a traditional CAD system. The parametric model also considers more sophisticated issues and automatically calculates the insulation properties and solar gain for each wall in the project. The morphological 3D model automatically generates parking, public spaces, water systems, street corners, and land-value maps to insure that the neighborhoods are not segregated by income. The process is self-organized and performed so the relationships of courtyards and street are maintained but making sure that we can never encounter an exact repetition.

Finally, the students can test in 3D flight, which renders the configuration and environmental performance of each interior space, wall, and public space. Every space is treated differently based on the performance criteria set in the parametric system, moving the design morphology of the project closely to the vernacular experience found in traditional Chinese cities.

AUTOMATING CONSTRUCTION

Automating Construction in Japan

Most of the parametric discourse emerging in architecture today and described above belongs to the design automation type. However, from the other side—the construction/engineering—side many other ideas have also emerged and materialized. The Japanese construction industry since the late 1980s has led the world in construction automation. Most large construction companies such as Taisei, Obahashi, Takenaka, Shimizu, Kajima, Tokimec, and Fujita had major automation projects such as automated erection projects, automatically controlled machines that replaced some manual construction tasks like welding, steel erection, or concrete placement, to avatar-robots controlling heavy machinery in the job site.

By 1999 the Japanese construction industry could account for more than 550 systems for unmanned operation and automation of construction and civil engineering operations (Obayashi 1999). Today research centers in Japan have advanced investigations that test and use humanoid robots in construction. Despite these advances, fully automated Japanese construction systems have failed to produce significant gains and are hardly exportable to other countries.

Pre-fabrication and Modularization in the United States

Most of the computerization metaphors found in Japanese construction projects are related to bringing automation into the construction site. Instead, pre-fabrication and modular construction in the US, Europe, and particularly China seem to offer a more viable vision for the automation of construction. In the past three to five years, a significant number of construction sites in the US have become increasingly assembly sites in which elements such as HVAC systems, wall units, even restrooms components are pre-fabricated off site, reducing safety, cost, waste, and the length of projects. In 2009, 73% of contractors surveyed in the US believed that BIM would allow them to increase prefabrication (McGraw Hill 2009). In another (2011) survey of contractors using pre-fabrication and modularity 66% of project schedules had been reduced, 35% by 4 weeks or more, and 65% project budget had been decreased, 41% by 6% or more (McGraw Hill 2011).

Pre-fabrication and Modularization in China

In China the Company Broad Group has stunned the category of pre-fabrication and modular construction by completing several buildings in record time. In 2010 they built a six-story pavilion for the Shanghai Expo in one day, and in 2011 they assembled and completed a 30-floor hotel in 15 days. The Broad Group has developed since 2009 a modular pre-fabrication system in which around 93% of the labor-hours of construction are spent in a factory—compared to only around 40% traditionally obtained in the west. The time spent at the construction site is minimal, thus reducing construction errors, delay, accidents, construction site pollution, and site waste.

The Broad Group claims that by controlling the construction via pre-fabrication and introducing their energy equipment, they can also improve significantly the energy efficiency of their buildings, gain better control its life cycle, and greatly reduce CO2 emissions. Broad Group claims that their latest 17,000 sq. ft. hotel constructed in 2011 is five times more energy efficient than traditional buildings, can resist a magnitude nine earthquake, and that the air inside the building is 20 times purer than outdoor air.

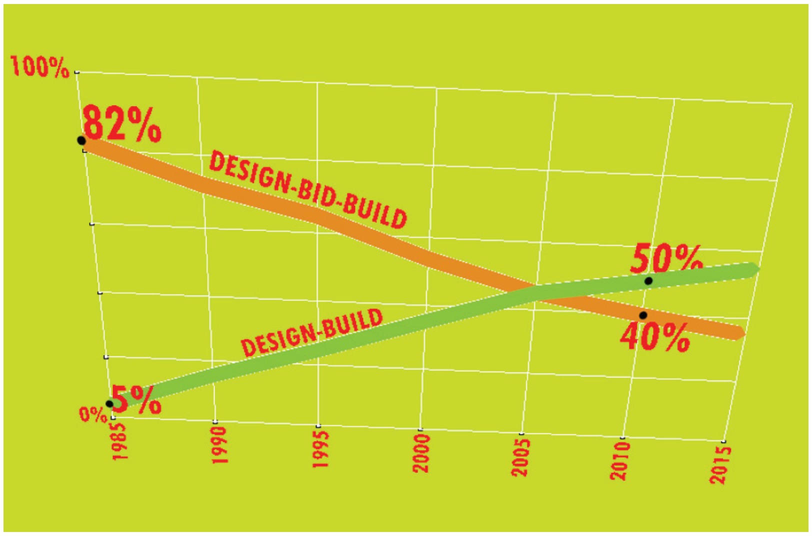
DESIGN AUTOMATION VERSUS CONSTRUCTION AUTOMATION

The design automation led by Architects and the construction automation projects led by Engineers are not interrelated. Both endeavors have followed their own cultural biases and will undoubtedly clash in this decade. Which automation agenda will win? It is not difficult to argue that Architects have the weakest arguments when looking at cost issues. Potential efficiencies gains by automating design itself are very modest at best when you consider the overall costs involved in construction.

For every $1 that is spent in design, $20 is spent in construction, and $60 is spent in the operation of the building. Moreover, the biggest expense in construction in developed countries is construction labor. On average in the US for every $1 dollar spent in materials $10 is spent in construction labor. If more than 90% of the labor-hours are spent in manufacturing facilities, as in the case developed by Broad Group in China, it means that a significant amount of labor cost could be reduced as robotic technology explodes during this decade. Without much speculation one can clearly argue that we might began to see large global design-build companies like Broad Group from China taking over all kinds of projects and controlling significant market share of the design and construction industry.

Large Design-Build Players Dominating the World of Construction

Architectural firms have survived in the past 100 years in a much segmented construction industry with hundred of thousands of relatively small construction companies and vendors. The business plan of Broad Group is to capture 30% of the construction market by 2030. The potential rapid consolidation of big players using modular and pre-fabricated systems in the construction industry would further consolidate the trend toward design-build which has been developing in the US in the past 25 years to the detriment of the role of architects. In 1985 more than 85% of buildings were



01

delivered as design-bid-build contracts while design-build contracts represented only 5% of the total projects.

Architects had a key role as coordinators of design-bid-build contracts. Instead the vast majority of design-build contracts are highly dominated by contractors and engineers who develop direct contracts with the client. Today close to 50% of the buildings constructed in the US are delivered using design-build contracts. Major questions will emerge about how architectural thinking, even though highly automated, can evolve in this new plausible scenario without merging into the powerful paradigms brought in by a production system highly controlled by contractors and engineers.

PARAMETRIC AND ARTIFICAL INTELLIGENCE

First Step of Artificial Intelligence

Basic scripting and parametric thinking has been developed with some success in a number of places in architectural academia and practice in the past decade. However, it seems that these design automation endeavors are still working under the old premises of how we have always looked at the role of architects or architecture. Contemporary parametric works have a novelty and a wow-aesthetic effect in some. Some architects are enthusiastic about parametric range from those interested in formal investigations to those searching for new ways to construct. These architects feel that they can be in more control of many factors of design that are not accessible by highly intensive manual 3D modeling.

There are many alarmist and contradicting claims. Some shout that this is totally revolutionary, the final frontier, while others argue with disdain that this is the end of the creative process. However, parametric is just one more

Figure 1: Graph showing the rise of design-build delivery system in the US, 1985 to 2015.

step in the evolution of human-computer interaction. It is very much dependent of the accelerating growth of computing power that is sweeping many industries. Parametric, as we are observing it today, is the most primitive level of artificial intelligence. We are beginning to enter into the first part of the parametric age in architectural design with parametric formalism, parametric BIM, parametric meta-heuristics, and parametric topology. This first age will be characterized by allowing architects to make more explicit their design process and by promoting collective intelligence. As analyzed in this paper, the current stage will be further defined by the new advancements in the automation of construction.

Second Stage of Artificial Intelligence

A second stage of impact of artificial intelligence on architecture will begin to occur when computers will be able to analyze the processes of design and construction. The computer would have to be designed to perform concept learning and concept formation. This might seem far for architects today, but it is quickly becoming a reality in many professions. Algorithms are already picking up start-up companies for venture capital firms, and they are automating the discovery processes of many large practices in the legal community. Complex algorithms are already replacing engineers in tasks such as chip design, substituting journalists in writing sports news, grading English essays, developing patrol routes for the Los Angeles police. Notice that IBM's Watson supercomputer beat human competitors at "Jeopardy" just after two years of training.

Third Stage of Artificial Intelligence

A third stage of artificial intelligence will emerge when a device is no longer programmed and evolves primarily by learning. Computer power today is far from achieving the third stage of artificial intelligence. But in a not-distant future this might be possible. By 2029, computer power will allow us to reverse-engineer the human brain, which will be a significant advancement. In the mean time we are bound to begin to open the design 'black box' and develop the initial steps of a parametric knowledge base.

CONCLUSION

In this paper we argued that automation processes in architecture will soon collide with efforts promoted by a more powerful constituency of constructors and engineers. We are just entering the parametric stage in architecture, but with the current accelerated advancements in process-oriented algorithms, networks, robotics, computer vision, and computer learning we will soon began to experience the beginning of the second stage of artificial intelligence. While parametric only addresses the domain in which architects work (like 3D modeling and associated information), in the second stage of artificial intelligence the computation domain is much more focused on understanding processes, the intelligence of processes. In this case the intelligence of the whole design construction process: design, specialties, procurement, and construction. We are currently in the first steps of creating a design intelligence that soon will be able to be coded by many authors, aided by computer software, and transformed over time. ◆

REFERENCES

Coates, Paul. *Programming.Architecture*. London: Routledge, 2010.

Derix, Christian. "Mediating Spatial Phenomena through Computational Heuristics." *ACADIA 10: LIFE In:formation* (2010).

Eastman, Charles. "Automated Assessment of Early Concept Designs." *AD Architectural Design*, 79 (2009): 52–57.

Mcgraw Hill. *Smartmarket Report. The Business Value Of BIM: Getting Building Information Modeling To The Bottom Line.* Mcgraw Hill, 2009

Mitchell William J., McCullough, Malcolm, and Purcell, Patrick. *The Electronic Design Studio: Architectural Education in the Computer Era.* Cambridge, MA: MIT, 1990.

Obayashi, S. *Construction Robot System Catalogue in Japan.* Tokyo, Japan: Council for Construction Robot Research, Japan Robot Association, 1999.

Schumacher, Patrik. "Parametricism: A New Global Style for Architecture and Urban Design." *AD Architectural Design,* 79.4 (2009).