arq (2017), **21.1**, 5–9. © Cambridge University Press 2017

perspective

Reflecting critically on architecture and digital technology infrastructures in the history of computational design

Processes and practices in computational design

Nathalie Bredella and Carolin Höfler

Every architectural design emerges from a process. The different tools and media constitutive of these processes in turn foster approaches to architecture, as well as the creation of new categories of knowledge. With the progressive development of computer-based design techniques, the contemplation of the procedural aspects of architecture becomes increasingly significant for the production and reception of architecture.

It is from this perspective that this special issue sets out to examine the specific roles that processes and practices play in computer-based design by seeking to illuminate those techno-cultural contexts and historical and intellectual bonds that unite them. Which traditions and strategies, and what historical correlations among architecture, culture, and technology, have motivated and shaped the development of computer-based design processes? Which critical methods and concepts can then be developed when focusing on architectural analysis while also taking into account recent theoretical discourses and technological advancements? Using oral history and case studies, as well as theoretical reflections from the perspective of architectural, media, and cultural theory, this issue seeks to offer insights on the history of computational design by emphasising the role of technical infrastructures, as well as architecture's interaction within heterogeneous networks, including economic, legal, and technological contexts. These networks inform the development of computer systems, which are themselves characterised by their own building techniques; together, these networks and systems regulate design. In this context, the collection of pieces in this issue also grapple with software automatisms and those procedures that operate outside the boundaries of direct control. As the focus shifts towards knowledge practices and insights gained during the process of design, the question arises as to how industrial, technological, and socio-economic contexts are inscribed in knowledge practices characteristic of design. Furthermore, the cultural paradigm of self-generating form and unpredictability of design asks in what ways computational design practice can be described as an epistemic practice.

Computation and questions of control

Because architecture regulates various aspects of human life, it is thus related to questions of politics and control. In regard to the political history of computers, Fred Turner has demonstrated that computational networks, once the artifacts of a Cold War technocracy, became increasingly linked to libertarian ideas in the public sphere during the 1990s; at the same time, the meaning of information technology shifted as a networked culture of research migrated from the weapons laboratories of the Cold War era towards corporate and public life.[1] In the context of the more widespread use of digital technology, Turner points out how, with the widespread use of the Internet and the World Wide Web, ideas about a more democratised society based upon informational networks filled the air during the mid-1990s. Quoting Nicolas Negroponte at MIT, Turner shows how technological development in the postwar era was connected to the belief that the so-called 'digital revolution' would lead to playful, self-sufficient collaborative networks with flattened hierarchies.[2]

The Expo '67 in Montreal provides an example of how information technology was linked to environmental and energy control, suggesting that a system of control would allow for better living conditions and a more equal distribution of resources worldwide. Cornelius Borck recounts that the Expo '67 was itself a cybernetic spectacle acting as an enlightenment as well as an entertainment machine where the visitor, vicarious for the 'New Man', became the object as well as the observer of feedback loops within this cybernetic spectacle. As such, cybernetic and pop culture merged in a multimedia spectacle fascinated with the control of goods, traffic, as well as visitor flows.[3] Expo '67 thus foreshadowed more recent discussions about information processing, visualisation, and control. This historical shift from the military toward public control and collaboration, as well as popular culture, becomes ever more significant when looking at design

doi:10.1017/S135913551700029X

processes, as the control systems become effective under the banner of 'network,' which Bruno Latour has termed 'worknets'.[4] This is also because politics imbedded within the infrastructures are easily overlooked in discussions about open access, political transparency, and digital collaboration.

Writing about the so-called military industrial complex and analysing the corporate architecture in the United States after the Second World War, Reinhold Martin shows how architecture played a crucial role in the postwar landscape, when corporations used the distribution of objects, images, as well as discourses to define social as well as political relations.[5] What then do these structures imply for analysing architectural practice, and how might one conceptualise the design process?

Computational design as an epistemic praxis

Computer-based design and its associated screen operations appear at first sight to be a kind of (inter) action with objects and with the characteristic of rationality, which is atypical for architectural design. Surpassing existing conditions is a characteristic feature of design, and the process of designing has, upon the assumption of generating something new, a distinct character of being non-technological. It is therefore rather a process of modelling in the manner of *bricolage*.[6] In its core characteristics, this process is defined by a transitory nature and uncertainty, and is oriented towards still-unknown things with blurred perimeters and stages – thus oriented toward those 'epistemic objects' described, with regard to scientific research, by Hans-Jörg Rheinberger.[7] Rheinberger develops an epistemology of experimentation, emphasising that research should be treated as a process for producing epistemic things. According to Rheinberger, by focusing on 'the local, technical, instrumental, institutional, social, and epistemic aspects' of experimental activity, a shift in perspective 'from the actors' minds and interests to their objects of manipulation' occurs, leading to 'a history of epistemic things'.[8] In this context, the epistemic object 'embodies [...] what one does not yet exactly know. [...] [It] is therefore necessarily underdetermined [...]. The technical objects [...], in contrast, are characteristically determined. They are the instruments, apparatus, and other devices [...]'.[9] For architectural research Rheinberger's approach offers the possibility to capture design strategies from within their own histories by identifying the apparatus of design as a heterogeneous ensemble of materials, practices, tools, institutions, and historical discourses.

1 SOM architectural studio, 2014. Photo: John Hill/World-Architects.

At first sight, the technological objects applied during computational processes differ from epistemic objects because they produce determined outputs. The question arises however, whether the idea of designing as an epistemic process can be brought into accordance with the characteristic of computer-based design; and if yes, to which idea of computer-based design processes it applies.

In their 2009 study *Knowledge Practices in Design: The Role of Visual Representations as Epistemic Objects,* Boris Ewenstein and Jennifer Whyte describe drawings and architectural models as incomplete visualisations which call for further development and final completion through the knowledge of and interpretation by the actors involved *[1]*. They write that the drawing 'as epistemic object actively draws attention to its own incompleteness and poses the question back to the practitioner for further development. [...] the drawings hide as well as reveal information and need constant interpretation.'[10] In the context of computational design, the question arises as to whether room for interpretation – necessary to allow for design to be understood as an epistemic practice – remains. An understanding of design as epistemic practice would provide insight on questions of agency within design and the interrelations between explicit and implicit forms of knowledge, as well as the more invisible rules, such as building regulations and economics that guide design.[11]

Parametric modelling: options and decisions

With the rise of computational techniques during the 1990s, architects, engineers, and software developers increasingly questioned how the design process as well as visualisation techniques were challenged by computational techniques.[12]

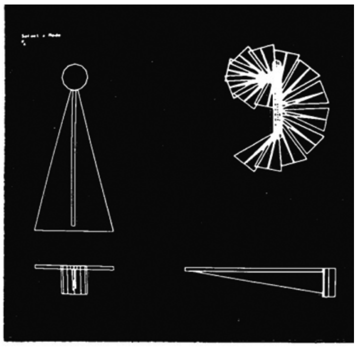
During this time, the development of 3D-modelling software promised new forms of communication that were based on geometrical models, to which other information relevant to design could be related. This was based on the idea that architectural design could be displayed and visualised by a single two-dimensional object from which drawings and other

https://doi.org/10.1017/S135913551700029X Published online by Cambridge University Press

```
POLY PROCEDURE spiral.step(POLY centre;
        REAL riser,radius,r,angle,th)=
    BEGIN
    POLY support =
        triangle(radius*0.95,-riser*0.8,th);
    POLY collar = column(12,riser,r);
    POLY plate = wedge(radius,th,angle);
    ! return the result of shape operations;
    CUT centre FROM  COMBINE collar WITH
          COMBINE support WITH plate
    END;

! To make spiral staircase, (dimensions in inches)
  SET PROCEDURE spiral.stair(ht,radius,angle)=
    BSET; INTEGER numsteps; REAL riser;
    numsteps ← ht/8.0;
    riser ← ht/numsteps;
    POLY centre = column(12,ht+32.0,5.0);
    POLY step = spiral.step(centre,
        riser,radius,3.0,angle,0.625);
    FOR i TO numsteps
        DO COPY step=(0,riser*i \0,angle*i)
    ESET;

  SET stair1 = spiral.stair(100.0,46.0,30.0);
```



2

2 Chuck M. Eastman, *Building Description System* (BDS), 1975. The input on the left generates the spiral staircase on the right that can be adjusted parametrically. Charles Eastman, Max Henrion, 'GLIDE: A Language for Design Information systems,' in *ACM SIGGRAPH Computer Graphics*, 11, 2 (1977): 24–33 [p. 33].

information can be extracted. This is the basic idea of what has been known since the early 1980s by the term of 'Building Modelling', which today, under the name of Building Information Modelling (BIM), has become a tool for optimising design and building processes, and decision-making *[2]*.[13] The model in this case is a single integrated database in which all relevant construction and building data are captured, combined, and interconnected, and which is available to all designers, engineers, and contractors. In short, this database serves as a solid tool for all the decision-making of all project participants.

Furthermore, the 3D building model allows for a close combination of design and fabrication. In the procedure known as *File to Factory*, geometrical and technical information is captured and collected in a data model which, using computer-controlled production technologies, is then transferred to a physical model or into a building component respectively *[3]*. In this process, drawing and model turn *operational* and hence lose any intrinsic value left open for individual interpretation. However, model and drawing should be clearly translated, and without any space for interpretation or misinterpretation, into producing and generating a three-dimensional object.

The current transition from computer-aided design to computational design in architecture thus represents a profound shift in design thinking and methods. Representation seems to be replaced by operation, and the crafting of objects is moving towards the generation of integrated systems through computational processes. By means of computational design and rapid prototyping, it is possible to skip various stages in the scale modelling process and to directly progress from the initial parameters to the 1:1 model. Information technology allows for design information to be formalised in a digital chain: to be forwarded, transformed, and turned into a numerically controlled code that directs a rapid prototyping machine.

The lack of a specific kind of interpretation and the digital aesthetics of immersion can actually be a hindrance in generating the distance required to enable a reflective and critical stance. It subsequently impedes the option of having divergent ideas and design approaches. It impedes the process of finding what the anthropologist Ignacio Farías has referred to as 'epistemic dissonance' – the productive and full exhaustion of alternate perspectives and knowledge patterns towards a yet non-existent object.[14]

In this debate on knowledge production and authorship, however, the effects of dynamisation and destabilisation of the design process by parametric modelling have been quite under-studied. But when it comes to the issue of epistemic praxis, particularly those dynamic effects are of paramount importance.

With the advent of parametric CAD software, what was being represented changed from being the result of a process to the description of a process that is editable and re-executable (see the conversation with Robert Aish in this issue of **arq**, pp. 65–73). The idea of designing as a linear process with distinct yes or no answers is thereby replaced by the idea of a continuous reciprocal flow of attempts, options, and alternatives.

By taking into account this generation of multiple variables by the aspect of epistemic dissonance, the following can be assumed: the central handling of architectural practice (of creating form and communication) is set up by design decisions. As a consequence, and in order to make decisions and to transfer uncertainty into certainty, it requires a multitude of equal possible alternatives for final resolutions.

Designing as epistemic praxis ultimately means to create a particular frame that has the potential of opening up those questions which would not have been considered if the design process had been handled by other means. A key principle that fosters this frame is the principle of exhaustion and permutation which posits that, given all possible options of a design, each or as many as possible outcomes should be applied and tested.

These design options come into being if architects directly act according to certain, and intended strategies, for example, through common office meetings in which the architects involved discuss, criticise, and elaborate on the given design from different perspectives.[15] It is on this principle of common discussion and debate that the actors involved generate a pool of design ideas, options, and alternatives.

Considering this background, computational design can be regarded as a socio-technical configuration which enables the generation of a multitude of possible design options, in particular when it comes to terms of evolutionary algorithms that are applied in the process. Through this evolutionary process of generating form, basic design information is combined and applied to by means of random procedure. Thus, designing means having innumerable variations of

3 Gramazio Kohler Research / Agile & Dexterous Robotics Lab, ETH Zürich, *Robotic Fabrication*, 2014.

form.

As such, epistemic praxis means that the architect acts with a high level of attention and responsibility. The philosopher of science, Michael Polanyi, described in his 1958 study *Personal Knowledge* the difference between two kinds of awareness: focal and subsidiary awareness.[16] Drawing your focal awareness to something also implies focusing it to a specific act, a distinct condition under given circumstances. With regard to design practice, this means that there is a clearly posited problem that has to be solved by the developer in a certain way and by creative, and not standardised, means.

Subsidiary attention, however, loosens this focus in order to get into the state of 'pending attention.' The latter condition gives space to a series of potential results, which are defined not by certainty, but rather by uncertainty. In all likelihood, a focused perception and attention would not take these results into account. Subsidiary attention, nevertheless, acknowledges these alternatives and brings the uncertain and unexpected to the surface. Subsidiary attention is therefore a helpful tool in anticipating and making tangible what was previously unforeseen. Transferred to the practice of architectural design, this means that the architect randomly observes something he or she had not originally sought, but which offers a new perspective on something not before anticipated or even imagined.

Thus, it seems that computational design has been specifically made for focal attention and the intended problem solving of design practice. But does computational design also allow for peripheral attention and perception?

This issue begins with Daniel Gethmann's case study on the work of the Austrian architect Bernhard Hafner, addressing how information-based design processes gained relevance on an urban scale (pp. 10–20). Gethmann explores how the cybernetic simulation of the interactions between urban structure, social activity, and human behaviour gained relevance in Hafner's 'Simulation of Alternative Urban Prototypes.' Daniela Fabricius examines Frei Otto's techniques, emphasising the mediation between incalculable material behaviour and calculable information (pp. 21–32). She furthermore addresses the aesthetics of representation, and its impact on computational design. Jan Müggenburg and Claus Pias discuss the utopian concept of cybernation in relation to the cybernetic research that took place during the 1960s, with a special focus on how the interaction between man and machine was imagined in the respective concepts in the future (pp. 33–44). This piece is followed by Susanne Hauser's observations on design practice (pp. 45–51). Reflecting on what characterises one of the most discussed cultural techniques, Hauser explores how different media are employed in what becomes a search for the boundary between knowing and not knowing.

In the first of three conversations, Robin Forrest, a founding member of the Computer-Aided Design Group at the University of Cambridge, discusses with Daniel Cardoso Llach the research networks of the 1960s and 70s that were central to the development of computer-based visualisation and production techniques (pp. 53–64). A special focus is placed on Steven Coons' and Pierre Bézier's techniques for surface representation in the aircraft and car industry, which led to developments of parametrically

https://doi.org/10.1017/S135913551700029X Published online by Cambridge University Press

controlled geometry. In the next conversation, Nathalie Bredella talks to Robert Aish, one of the main figures in the development of computational technologies in architecture since the 1970s (pp. 65–73). Aish explains the impact of architectural representation from model to program on architecture. In particular, he considers how the computational approach allows the architect to create a system of relationships, thus replacing the idea of designing as a linear process with distinct yes or no answers with the idea of a continuous reciprocal flow of attempts, options, and alternatives. Focusing on the entanglement between design practices and technological development, the final conversation with Reinhold Martin focuses on issues of architectural visualisation, in particular the visual infrastructure of perspective and the displacement of 'man' as an epistemic referent (pp. 74–80). Recounting the events at Columbia University's architecture faculty during the 1990s, Martin addresses questions of formalism, as well as access to a certain style/discourse through digital technologies.

Taken together, these essays and conversations provide a critical reflection on computational design by focusing on architecture's engagement with digital technology, translation processes, and feedback loops, as well as economic forces. Understanding some of the mechanisms characteristic of design practice as a cultural technique in general, and a computational one in particular, might thus allow the architect or designer to assume new responsibilities and to develop alternative strategies.

Notes

1. See Fred Turner's writing on Steward Brand and the *Whole Earth* network's role in orchestrating a dialogue between the military industrial research culture and the American counterculture between the 1960s and the 1990s, in: Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (Chicago, London: Chicago University Press, 2006).
2. Ibid., p. 1.
3. See: Cornelius Borck, 'Der Transhumanismus der Kontrollmaschine: Die Expo '67 als Vision einer kybernetischen Versöhnung von Mensch und Welt', in *Die Transformation des Humanen: Beiträge zur Kulturgeschichte der Kybernetik*, ed. by Michael Hagner, Erich Hörl (Frankfurt am Main: Suhrkamp, 2008), pp. 125–162.
4. Bruno Latour, 'Networks, Societies, Spheres: Reflections of an Actor-network Theorist', (2010), available online: < http://www.bruno-latour.fr/sites/default/files/121-CASTELLS-GB.pdf >, pp. 1–18 (p. 8.) [accessed 15 September 2016].
5. Reinhold Martin, *The Organizational Complex: Architecture, Media, and Corporate Space* (Cambridge, Mass.: MIT Press, 2005).
6. See: Susanne Hauser, 'Verfahren des Überschreitens. Entwerfen als Kulturtechnik', in *Wissenschaft Entwerfen. Vom forschenden Entwerfen zur Entwurfsforschung der Architektur*, ed. by Sabine Ammon, Eva Maria Froschauer (Munich: Fink, 2014), pp. 363–384.
7. See: Hans-Jörg Rheinberger, *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube* (Stanford, Calif.: Stanford University Press, 1997).
8. Ibid., p. 1
9. Hans-Jörg Rheinberger, 'Epistemic Objects/Technical Objects', in *The Anxious Prop. Case 2: Have Balls [Eccentric]* (Berlin: Euro Print, 2010), pp. 21–28 (p. 21).
10. Boris Ewenstein, Jennifer Whyte, 'Knowledge Practices in Design: The Role of Visual Representations as 'Epistemic Objects'', in *Organization Studies,* 30, 1 (2009), 7–30 (pp. 22–23).
11. See: the essays in Katie Lloyd Thomas, Tilo Amhoff, Nick Beech (eds.), *Industries of Architecture* (London: Routledge, 2016).
12. On the development of parametric design tools and the change in architectural and urban procedures as well as the architectural discourse see: Matthew Poole, Manuel Shvartzberg (eds.), *The Politics of Parametricism,* (New York: Bloomsbury Academic, 2015).
13. Phillip Bernstein, Peggy Deamer (eds.), *Building (in) the Future: Recasting Labor in Architecture* (New York: Princeton Architectural Press, 2010).
14. See: Ignacio Farías, 'Epistemic Dissonance: Reconfiguring Valuation in Architectural Practice', in *Moments of Valuation. Exploring Sites of Dissonance,* ed. by Ariane Berthoin Antal, Michael Hutter, David Stark (Oxford: Oxford University Press, 2015), pp. 271–289.
15. See Dana Cuff, *Architecture: The Story of Practice* (Cambridge, Mass.: MIT Press, 1992), pp. 1–4.
16. See: Michael Polanyi, *Personal Knowledge: Towards a Post-Critical Philosophy* (London: Routledge & Kegan Paul, 2005 [1958]), pp. 61–68.

Illustration credits
arq gratefully acknowledges:
ACM SIGGRAPH Computer Graphics, 2
Gramazio Kohler Research / Agile & Dexterous Robotics Lab, ETH Zürich, 3
SOM Architects, 1

Acknowledgements
This issue arose from the workshop 'The Fabric of Architecture: Digital Structures, Operations, and Institutions' funded by the German Research Foundation (DFG) and was supported by the Köln International School of Design, TH Köln. We thank Katherine Szadziewicz and Michael Fowler for their insights and assistance on the special issue.

Authors' biographies
Nathalie Bredella is Visiting Professor of Architectural History with a focus on media and gender studies at the Berlin University of the Arts.

Carolin Höfler is Professor of Design Theory and Design Research, TH Köln – University of Applied Sciences

Authors' addresses
Nathalie Bredella
n.bredella@udk-berlin.de

Carolin Höfler
hoefler@kisd.de