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The Aesthetics of (Digital) Machine Sculpture

Automatization, Mechanization, and Mathematization in Minimal, Serial, Conceptual, and Computer Art

Abstract

Today's 3D-printed digital sculpture can be traced back—not only in a technical sense—to the 1960s, when our digital culture developed. Using the examples of pioneers Robert Mallary and Charles Csuri, this paper reconstructs and distinguishes computer-based productions of sculpture, its reception, and its ontology. One focus is the discourse of sculpture, image, and form. A comparison with Minimal, Serial, and Conceptual Art is suggested not only because Minimal Art was a hot spot of sculptural discourse, but also because it reveals correspondences between digital and non-digital arts, which exist on the level of draft, production, and discourse: a creation with certain machines, mathematization, automatization, mechanization, and a 2D/3D-discourse.

It will be argued that the examined digital and non-digital artforms in the 1960s, the time of pre-post-digital art, are only understandable in relation to each other and their common historical context: cybernetics, systems theory, the Cold War, and computerization. Taking the cultural-historical and politico-economic context into account, it will be demonstrated that one can identify specific reactions to digital technology and media and its impacts on art and society—which is why I call the non-digital artforms "co-digital art."

Key Words

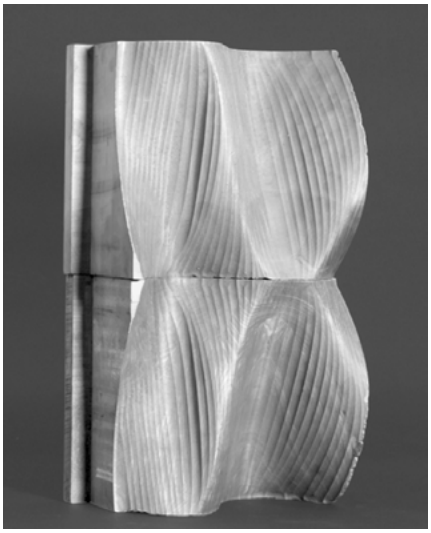
Computer sculpture, automation, 2D/3D, machine, form, co-digital art

Sculpture in the 1960s: Arrival of the Computer

Following the story of Charles Csuri that he posed for fellow artist and friend George Segal for his work *The Diner* (1964–66), the life-sized, figurative plaster sculpture in it represents an artist, who is sitting at a diner bar and who had studied at Ohio State University with a

focus on portrait painting and turned toward computer art in the 1960s.[1] After Csuri had started teaching at the same university, and around 1965 became interested in computer graphics and film, he made works such as *Sine Curve Man* (1967), which was awarded from *Computers and Automation,* and created—and this is of interest here—the computer sculpture *Numeric Milling* (1968) with an IBM 7094 computer system (figs. 1, 2).[2] So, Csuri not only acted as a model, but also developed a mathematical one. In this regard, together with programmer James Shaffer he published the paper "Art, Computers and Mathematics" (1968), where they wrote: "Our most recent project is sculpture using a 3-axis, continuous path, numerically controlled milling machine."[3] Numerical representation in connection with a computer is considered a characteristic of digital media.[4] George Segal, in turn, had made automation a subject in his figurative work *Laundromat* (1966–67).

1 Charles Csuri, with James Shaffer, *Sine Curve Man,* 1967, black ink, paper, Calcomp drum plotter model 565, punch cards, IBM 7094, 104 × 104 cm.



2 Charles Csuri, *Numeric Milling,* 1968, wood, 3-axis milling machine, IBM 7094, punch cards, 36 × 56 × 22 cm.

1 See Kerry Freedman, "Oral History Interview with Charles A. Csuri," Charles Babbage Institute, October, 23, 1989 (University of Minnesota, Minneapolis), pp. 1–35, here pp. 3–4, 14, https://conservancy.umn.edu/handle/11299/107236 (accessed April 6, 2021).

2 Anonymous, "Charles A. Csuri, Numeric Milling," Charles A. Csuri Project website, Ohio State University, https://www.csuriproject.osu.edu/Detail/objects/768 (accessed April 6, 2021).

3 Charles Csuri and James Shaffer, "Art, Computer and Mathematics," *AFIPS—Conference Proceedings* 33 (1968), pp. 1293–98, here p. 1297.

4 See Lev Manovich, *The Language of New Media* (Cambridge, MA/London: MIT Press, 2001), pp. 27–29.

In 1964, it was Donald Judd who reviewed Segal's *The Diner* in a commendatory manner, for what he argued was the tension between the real (size, appearance, and space) and the artificial (material).[5] In the same year, he penned his essay "Specific Objects" (1965), which served as a theoretical basis for (his) three-dimensional object art and as an attack against the well-established genres of painting and sculpture.[6] Last, but not least, at that time he also created his works—especially the bar-like series progressions like *Untitled* (1965) (DSS 84)—on the basis of numerical *schemes* and made use of fabrication.[7]

This was recognized by artist and theorist Jack Burnham, who argued in his 1968 book *Beyond Modern Sculpture*—a teleological history of sculpture since modernism in light of the development of technology—with a view to the above-mentioned progression: "More than anything else, the efforts of the Minimal or Object sculptors characterize the mathematical intentions of this decade."[8] We will come back to these intentions, especially those of the "sculptors," who are inappropriately called Minimal artists.

At this point, we can record the fact that the notion of sculpture was by no means homogeneous in the 1960s: at first, the modernist, especially figurative and nonfigurative handmade plastic art like that of Pablo Picasso, was discussed as sculpture as well as "construction-sculpture,"[9] which Clement Greenberg made out, for instance, in David Smith and which will be introduced in more detail. This broad range widens out in the second half of the decade through (Minimalist) object art and computer sculpture. This is documented by the inventory-taking exhibitions *The 1960s: Painting and Sculpture from the Museum Collection* (1967) at the Museum of Modern Art[10] and the *Annual Exhibition: Contemporary American Sculpture* (1968) at the Whitney Museum of American Art. In each of these shows, George Segal, Donald Judd, and Robert Mallary—a further computer sculptor, who will be treated here—were represented. Mallary exhibited in the Whitney show his "computer sculpture" *Quad II* (1968), the second one of the *Quad* series (fig. 3).[11] Like Csuri, he was an educated artist who got access to computers as a faculty member. In 1967, after he

5 See Donald Judd, "Local History" (1964), in Donald Judd, *Complete Writings 1959–1975: Gallery Reviews, Book Reviews, Articles, Letters to the Editor, Reports, Statements, Complaints* (Halifax/New York: The Press of the Nova Scotia College of Art and Design, 2005), p. 153.

6 For it and discrepancies between Judd's essay, works, and Minimal Art, see Michael Rottmann, *Gestaltete Mathematik: Geometrien, Zahlen und Diagramme in der Kunst in New York um 1960: Mel Bochner – Donald Judd – Sol LeWitt – Ruth Vollmer* (Munich: edition metzel, 2020), pp. 108, 116, 125.

7 See ibid., pp. 116, 181–92.

8 See Jack Burnham, *Beyond Modern Sculpture: The Effects of Science and Technology on the Sculpture of This Century*, 4th printing (New York: Braziller, [1968] 1975), p. 147.

9 See Clement Greenberg, "Sculpture in Our Time" (1958), in *Clement Greenberg: The Collected Essays and Criticism*, vol. 4: *Modernism with a Vengeance 1957–1969*, ed. John O'Brian (Chicago/London: University of Chicago Press, 1986), pp. 55–61, here pp. 57–58.

10 See "The 1960s: Painting and Sculpture from the Museum Collections," press release, Museum of Modern Art New York, June 27, 1967, https://assets.moma.org/documents/moma_press-release_326520.pdf (accessed April 8, 2021).

11 See *1968 Annual Exhibition Contemporary American Sculpture*, exh. cat. Whitney Museum of American Art New York (New York: Whitney Museum of American Art, 1968). The catalogue mentions *Quad III*, which is considered to be made in 1969. So I assume it was the very similar *Quad II*.

3 Robert Mallary, *Quad II*, 1968, computer-aided sculpture, plywood and laminate, IBM 1130, ca. 195.5 × 25.5 × 30.5 cm (without base).

had started his professorship of art at the University of Massachusetts in Amherst, he turned toward the computer, in particular with an understanding that the machine could generate and transform images.[12] In 1968, together with his son Michael Mallary and/or student programmers, he wrote the first version of his "computer sculpture program" TRAN2 for the local IBM 1130 system,[13] which was introduced into the market in 1965, and created with it, still without a screen, his first computer sculpture *Quad I* (1968)—just in time for presenting it at *Cybernetic Serendipity* in London.

Against this background, the following discussion will look at computer sculpture of the 1960s, which will be understood as an art form, but also foremost as a three-dimensional object. As computer sculpture emanates from a creative process that integrates a digital computer—which basically defines digital art—computer sculpture qualifies as a digital machine sculpture and an early field of three-dimensional digital image making. This study will especially be done because computer sculpture has been treated in art history, but has received less attention than computer graphics. It may be due to a quantitative asymmetry of artworks and their historical technical *dispositif* as well: special machines for graphics (e.g. the plotter) had been developed, but comparable output devices for three-dimensional objects didn't exist, and only a few protagonists gained access to the milling machines of industry.

12 Robert Mallary, "Computer Sculpture: Six Levels of Cybernetics," *Artforum* (May 1969), pp. 29–35, here p. 31.

13 Ibid.

For a variety of reasons, computer sculpture will be related to Minimal, Serial, and Conceptual Art, which are closely connected in the second half of the 1960s.[14] The latter are regarded as central places for a (critical) negotiation of sculpture. Furthermore, what will be demonstrated is that parallel developments can be made out: a mechanization in the sense of an increasing use of machines, as in the fabrication of Minimal Art's objects, can be identified. It can thus be understood as non-digital machine sculpture, although it was brought into position against sculpture—thus we have two kinds of machine arts in play (yet the relationship between humanity and machine will not here be an issue per se). In addition to this, mathematization and automatization—both usually associated with the use of a computer—as well as a 2D/3D debate have to be mentioned, and each of these will be discussed. Last but not least, the connection between sculpture, Minimal Art, and information technology has been drawn (in the historical discourse).[15]

If sculpture in a broader, structural sense (à la Rosalind Krauss), which has been discussed via the "sculptural" (*dem* "*Skulpturalen*"), is pursued less here than a work-centered (*werkzentrierte*), object-oriented conception of sculpture—although a tendency of "liquefaction" of the object has been described in the historical discourse[16]—this is because the latter can be found in both fields of machine sculpture.

One focus of what follows is the discourse of sculpture, image, and form in light of technology, in which a predominating understanding of sculpture since modernism once again considerably changed in the context of the use of (digital) machines. Another focus is the creative and production processes, ending in sculpture as object. An aesthetics of (digital) machine sculpture demands this because the artwork is determined by its machinic production, and refers to it, which is preserved in its form and materiality. "In the aesthetic presence the production is constitutively forgotten," as Sebastian Egenhofer has explained. "But it belongs to the structure of the artwork, to touch and turn the border of this oblivion."[17] It remains to be shown with the examples below how this applies to technology-based art from the 1960s.

All art movements that are treated here—and this is the claim—have to be thought of in a common historical ground, which prevails all the more if one takes into account the sociopolitical and cultural-historical situation in the United States—keywords here are cybernetics, systems theory, computerization, and Cold War—and the embedding into the historical *dispositif* of production. There was a critique on and a reflection of production and technology in art tied to it there, which will be considered here.

14 See Edward Shanken, "Art in the Information Age: Technology and Conceptual Art," *Leonardo* 35, no. 4 (2002): 433–38.

15 See, e.g., Jack Burnham, "Systems Esthetics," *Artforum* 7, no. 1 (September 1968), pp. 30–35, p. 32.

16 See Rosalind Krauss, "Sculpture in the Expanded Field," *October*, no. 8 (1979): 30–44. See Burnham, "Systems Esthetics," 1968, pp. 30–35; Martina Dobbe and Ursula Ströbele, "Gegenstand: Skulptur," in *Gegenstand: Skulptur*, ed. idem (Paderborn: Wilhelm Fink, 2020), pp. 1–16.

17 Sebastian Egenhofer, *Produktionsästhetik* (Zurich: diaphanes, 2010), p. 7. Translation by the author.

It will become evident that the examined (digital) machine sculpture of the 1960s—when today's digital culture significantly started to develop—can be understood as a prehistory of today's 3D-printed sculpture, like that of Karin Sander or Nick Ervinck, not only in a technical, but also in a conceptual respect.

This will be argued in a theoretical manner and a historical reconstruction. Let's now closely examine Csuri's and Mallary's computer sculptures,[18] whose same date of origin invite a comparison. A first contextualization in the discourse of sculpture will be revealing.

The Otherness of Computer Sculpture(s)

In a formal respect, both artists' computer sculptures follow a certain tradition of modernity but can also be related to the already mentioned "construction-sculpture," which was announced by Clement Greenberg in 1958 again as new and forward-looking.[19] Since modernity, sculpture no longer needed to be mimetic and monolithic.[20] Both computer sculptures make use of the former, but not of the latter. Csuri's *Numeric Milling* is made of unpolished wood; it is small-sized and compact (33 × 56 × 22 cm) and without a pedestal. It has convex and concave parts, and the latter show groove-like depressions. Like Constantin Brâncuși, who was mentioned by Greenberg as a transformer of the human figure into geometric, abstract forms,[21] Csuri kept the shape blocky and used a single material. Contrary to this, Mallary used expanded possibilities. The life-sized, pole-like sculpture *Quad III* (213 × 35 × 33.6 cm) which is very similar to the already mentioned *Quad II*, seems to surpass its pedestal and to head in a meandering and line-like manner for height. One could get the impression of a potentially infinite continuation, as in Brâncuși's *Endless Column*, but for a thick plug at the upper end that closes it off and, pushing downward in accordance with gravity, opposes the upward soaring. The material and color of *Quad III* no longer appear—as in construction-sculpture in which color could also a be applied[22]—as a unity.

The computer sculptures nowhere near fulfill all the characteristics of construction-sculpture.[23] But Csuri, Mallary, and the "constructor-sculptor" are unified by an open-mindedness toward new techniques and materials: "a work or its parts can be cast, wrought, cut or simply put together: the new sculpture is not so much sculpted as constructed, built, assembled, arranged."[24] To distinguish sculpture and plastic art (*Plastik*) just in the manner of subtractive or additive work by "carving and modeling" had become anachronistic.[25] In that way, Mallary could take up his assemblages, which he described as a "combining and

18 Two male artists are treated here, so a desideratum would be to identify and research female artists working in the 1960s as computer sculptors.
19 See Greenberg, "Sculpture in Our Time," 1958, pp. 57–58.
20 Ibid.
21 Ibid.
22 Ibid.
23 Ibid.
24 Ibid., pp. 58, 61.
25 Ibid., p. 58.

recombining" of (found) objects.[26] Furthermore, the computer sculptors could build on the material culture and practices of construction-sculpture. Traditional materials like "stone, bronze and clay" would be substituted by "industrial materials like iron, steel, alloys, glass, plastics, celluloid, etc., etc., which are worked with the blacksmith's, the welder's and even the carpenter's tools."[27] Thus Greenberg attested to "the medium a new flexibility" and "a wider range of expression."[28]

The two computer sculptors belong to that group of artists in the 1960s who mainly speak euphorically and assertively about the possibilities of computers in art: technical restrictions, which they also mentioned, were understood as challenges[29]—let's keep in mind that both artists did research at universities. However, when their forms and materials seem to be modern, this must be seen in the context of the technical *dispositif* of the 1960s. In a paradoxical manner, the surfaces provide information about the difference of their production methods: *Numeric Milling* shows traces of the milling machine, whereas the smooth, shining paint (*Fassung*) of *Quad* results from the artist's manual work. It was an aesthetic decision by Csuri because the milling machine could produce smooth surfaces.[30] With the machinic *sculptura* an impression of direct carving could even appear—a method without a model as an intermediate step. At the same time, the decisions of the artists were bound with the possibilities of technology. So, Mallary's program *TRAN2* could calculate forms, which could be printed with an inkjet printer, but it was Mallary himself who had to transfer them onto a plastic or plywood panel, cut disks out, and stack and cover them with the help of a metal axis.[31] The 48 to 100 contours, which could be realized with the IBM 1130 system, where not enough to reach a smooth, continuous form as Mallary explained.[32]

Here, a first differentiation of computer-sculpture can be done with a view to its production and the role of the computer: Csuri produces the object directly with the machine, Mallary develops forms with the computer, and his subsequent manual process could be described as plastic-constructive. In each case, the computer enabled just a partial automatization, and the creative processes were manual-machinic or analog-digital hybrids in a pre-postdigital (art) world.

26 See Copper Giloth and Justin P. West, *Robert Mallary: Pioneer in Computer Art 1992*, Vimeo video, 26:53, no date, uploaded by Copper Giloth, https://vimeo.com/133915501, here 3:24 (accessed December, 27, 2021).

27 See Greenberg, "Sculpture in Our Time," 1958, pp. 58–59.

28 Ibid.

29 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, p. 1298; Mallary, "Computer Sculpture," 1969, pp. 32–33.

30 See the Charles A Csuri Project website, https://csuriproject.osu.edu/index.php/Detail/objects/768 (accessed April 11, 2021).

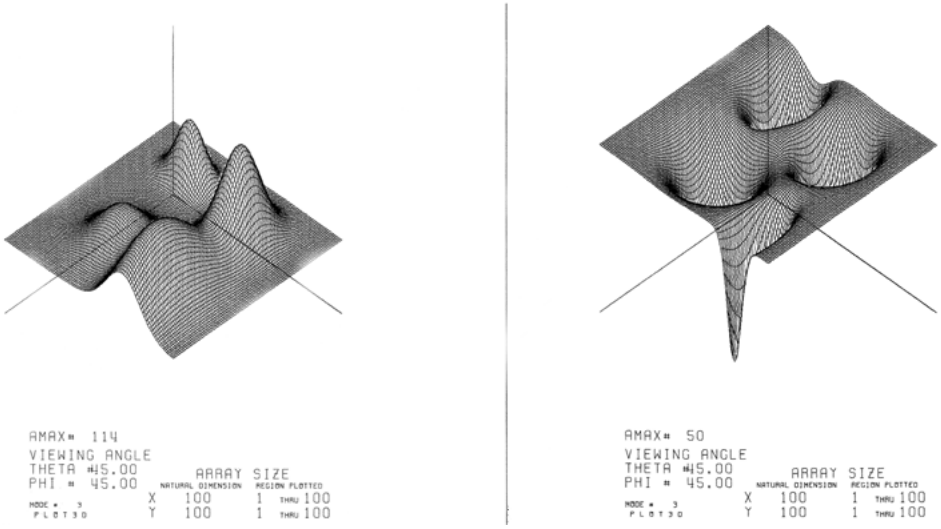
31 See Mallary, "Computer Sculpture," 1969, p. 32.

32 Ibid., p. 31.

Ontological Aspects of Computer Sculpture

For Charles Csuri and Robert Mallary, the computer possessed outstanding significance because of its potential to generate multiple forms, also new ones, in the sense of the gestalt of an object.[33] Referring to this in the historical discourse, which was characterized by thinking about forms, the following question was relevant: Which (artistic) media can be operated by computer and controlled and modified dynamically with the passage of time? Visual forms could be displayed with the principle of light on a screen in two dimensions or with a projection in three dimensions—as both artists mentioned[34]—but in each case only in an ephemeral manner. They could permanently be supplied to perception with a plotter in two dimensions (fig. 4) and with a milling machine in three dimensions. With these different appearances a question of ontological modes arises: What was the historical conception of computer sculpture?

In contemporary theory of digital images, which is more applied to computer graphics, it is common to think in a binary relation of image and code, thus ascribing the digital medium a dual nature.[35] It is in dispute whether a materialized and externalized image



4 Charles Csuri, plotter drawing of *Numeric Milling,* 1968, ink, paper, Calcomp Drum Plotter Model 565, punch cards, IBM 7094.

33 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, pp. 1294–95. Mallary; "Computer Sculpture," 1969, p. 31.

34 Ibid.

35 Actually, there are more relevant elements like diagrams, programs, etc. See Michael Rottmann, "Programm und Diagramm: Überlegungen zum digitalen Bild und zur Automatisierung anhand der Computergrafik der 1960er Jahre von Frieder Nake," *Kunstgeschichte Open Peer Reviewed Journal* (December 7, 2021): 1–23, here 4, https://www.kunstgeschichte-ejournal.net/589/ (accessed December, 7, 2021).

outside the computer system can be regarded as a digital one. This is furthered by the fact that otherwise its specific digital technical conditionality would remain unconsidered; the counterargument is that an external image, other than an internal one, could no longer be processed.[36] In any case, code and image—which can be also three dimensional—are in a close but "paradoxical relationship":[37] the image is caused by the code in an arbitrary way and refers back to the latter—if it can be identified as coded.

Csuri and Mallary share an awareness of the connection of sculpture and code, they distinguish "code," "program," "data," and "sculpture," not least because they were both programming or were otherwise rather involved.[38] Nevertheless, they understood computer sculpture as a three-dimensional object. The ontological problem, appearing with computer sculpture, was not treated explicitly in the American discourse of sculpture of the 1960s to my knowledge.[39] However, the artists examined here exemplarily show a distinction of the following states of computer sculpture: (1) the external sculpture as a real three-dimensional object, generated with a computer system and produced by machine and/or hand afterward (computer-generated/produced sculpture). (2) The internal sculpture—we would talk nowadays about a virtual object—as a pictorial object, which is processed within a digital system and becomes visible, for example, on a screen; as Csuri could not display the "[m]athematically generated surfaces," they were printed.[40] (3) A mathematical and algorithmical mode of being can be identified as associated with it. Addressed here are the program and the data of a sculpture, whose basis is mathematical, because it is a central property of the computer to automate calculations; algorithms for the calculation of mathematical issues could moreover be included in what was mentioned as a basic principle for a (parametric) generation and examination of visual forms.[41]

In research literature a "dematerialization of art" (Lippard/Chandler) and information technology have been considered together, especially with a view to the transformation of an artwork into code and information.[42] With the same direction of impact and in the context of his systems aesthetics for painting and sculpture, Jack Burnham described a change

36 Ibid.

37 See Claus Pias, "Das digitale Bild gibt es nicht – Über das (Nicht-)Wissen der Bilder und die informatische Illusion," *Zeitenblicke* 2, no. 1 (May 8, 2003), n.p., https://www.zeitenblicke.de/2003/01/pias/pias.pdf (accessed March, 22, 2008). Translated by the author.

38 They also used technical terms like "processing" and "transformation." See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, p. 1293; Mallary, "Computer Sculpture," 1969, pp. 29–35.

39 The difference between "object" and "software" was discussed. See Les Levine, "Systems Burn-off X Residual Software," in *Software: Information Technology: Its New Meaning for Art*, ed. Jack Burnham, exh. cat. The Jewish Museum (New York: The Jewish Museum, 1970), pp. 60–61. For a discussion in the German discourse (e.g., by Herbert W. Franke) see the essay of Ursula Ströbele in this volume.

40 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, p. 1297.

41 Ibid., p. 1294. See Margit Rosen, "A Record of Decisions," in *Charles A. Csuri: Beyond Boundaries, 1963—present*, ed. Janice Glowski (Columbus, OH: College of the Arts, Ohio State University, 2006), pp. 25–45, 34–35, 42.

42 See Shanken, "Art in the Information Age," 2002.

from the "unique work" to an "unobject" in the way of a "liquefaction";[43] Robert Morris, for instance, had transmitted the working plans of his *L-Beams* so they could be rebuilt on site without transporting them between the exhibition venues[44]—this is close to the idea of sending data and 3D-printing a work.

Accordingly, it is remarkable that, although Csuri was interested in movement, variation, and transformation and thus in dynamical forms—we remember his interest in portraiture—which computer film enabled him to pursue, Csuri made a permanent sculpture.[45] It is insightful to speculate about the reasons: the production of a three-dimensional object could be motivated by Csuri's technical research. Such an object was permanent, experiential, exhibitable, and tradable—this artwork-oriented attitude could be rooted in Csuri's education. We have to consider that in the 1960s a real (but not too big) sculpture—from today's perspective perhaps surprising—could circulate better than a virtual one, because computers, if at all, were difficult to transport, generally not networked, and mostly not equipped with a screen, and thus hardly usable in exhibitions.[46] In Serial and Conceptual Art, the work-centered concept of art was relativized by the emphasis on order or the idea, as well as the transition to languages, diagrams or even certificates, which also attacked the suitability for the market. It remains an open question whether a virtual sculpture would have been accepted as art in the 1960s; it anyhow could have been reproduced easily with a data carrier, but not protected with the technology of non-fungible tokens (NFT). In any case, computer sculpture as a three-dimensional object could be reconnected to an established genre and in such a way legitimized and more easily fed into the discourse of sculpture.

Let's now turn toward the mathematical characteristics and art experience of (computer) sculpture and its theorization, because, with the machine, mathematics is also in play: not only is the construction of a machine prepared by calculations, but with digital machines at the latest computing also became an essential task.

Mathematical (Computer) Sculpture

If one asks for the experience of an external computer sculpture, one can assume methodically initially that it differs from that of a traditional sculpture. Therefore, specific properties have to be identifiable on a phenomenal level, otherwise the respective experiences would coincidence.

Specifications could be: (1) traces of the (technical) production method, (2) materials and forms, as well as (3) their mathematical/coded basis. An identification due to previous knowledge, for instance via discourse or provided by additional information like photo-

43 See Burnham, "Systems Esthetics," 1968, p. 32.
44 Ibid.
45 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, p. 1295.
46 Here, it proves true that art history benefits from precise argumentation concerning historical technology.

graphs, diagrams, and texts in the exhibitions of Serial and Conceptual Art, is not meant here. Arguing with sculpture as an object reminds us that its infrastructure or display can also be decisive: for instance, is the computer relation of a virtual sculpture on a screen (in an exhibition) evident. The sense of the introduced description, "computer relation" refers to a problem: a received computer sculpture can be made totally by machine (like that of Csuri or today's 3D-printed pieces) or partly by machine and partly by hand, when, for example, prefabricated elements were assembled. They can also be made totally by hand (like that of Mallary), when, for example, a computer-calculated and -generated form becomes artistically converted. One could distinguish between a digital sculpture and a quasi-digital sculpture, which are both computer-based sculptures, fully or partly made by machine, and a virtual sculpture in the sense of a computer-based draft, which serves as an intermediate step in a creative process, ending in a handmade sculpture. A crucial aspect—for the term "computer sculpture"—is that at least at one point of the creative process—in an interplay of artists, things, and techniques—the computer comes into operation, whose basic determination is numerical computation. In response to this, here I will focus on mathematization in the sense of a "synthetic math,"[47] as Robert Smithson puts it, not least because the other, above-named identifiers are not less problematic: the materials can, but need not be specific. While Csuri worked with the traditional material wood, which can be carved by machine, today's 3D-printing uses Acrylnitril-Butadien-Styrol (ABS), for instance, which can be glued. Likewise, the consultation of traces proves a delicate matter. When Robert Morris asks us to consider that new mechanical production methods in the art could eliminate traces of production,[48] he related this to manual work, that is why one has to object that exactly his detection can be a trace, to namely that of the machine. Moreover, we have to consider that manual work can be imitated with machines and machined precision can be imitated with manual work. The "problem of form" will be discussed more detailed now.

Questions of form and materiality, on production and perception of art as well as their complex interplays have been treated within Minimal, Serial, and Conceptual Art, in particular for three-dimensional objects on a numerical basis. Aiming at the realization of certain aspects within production and perception, especially neutrality and objectivity as well as a debate concerning European aesthetics (i.e., proportion),[49] Donald Judd and Sol LeWitt created since 1963—actually before there was a talk of Minimal and Serial Art—works like *Untitled* (1963) (DSS 41) and *Wall Structure* (1963) by numerical schemes and considered appearing effects, especially the relationship of form and order. It is insightful to contextualize computer sculpture with these processes, even though they were determined by other traditions and intentions/objectives, and the numerical schemes are not strict formalizations because they don't have to be executable on a digital machine. However, the same goes

47 Quoted in Rottmann, *Gestaltete Mathematik*, 2020, p. 18.
48 See Robert Morris, "Notes on Sculpture: Part III," *Artforum* 5, no. 10 (Summer 1967), pp. 24–29, p. 26.
49 See Rottmann, *Gestaltete Mathematik*, 2020, pp. 220–24, 289–93.

for the digital code, depending on the way of production of a computer sculpture, or rather the degree of automatization.

Since the beginning, the unusual forming of the (pre-)minimalistic objects aimed at visual exploration of their structure, especially by offering shadows, reflections, and parts for looking at, through, or inside in an interplay with the three-dimensionality. In such a way, they aimed at the relation of seeing, thinking, and knowing. The genesis of a form out of manifold impressions corresponds to the problem of constancy of form (*Formkonstanz*), which was discussed in Rudolf Arnheim's Gestalt-based theory of perception. He pointed out that form and color play an important role in perceiving an object, but also in the context of visual thinking.[50] Another important issue was explained by Donald Judd: a numerical order could be realized and could compete against the form or even dominate it.[51] Thus, a form could be relativized—as the Minimalists also argued—not only by color and materiality.[52] Depending on the ontological model on which it was based, this was contrary to an art based on factuality, but was beneficial in the intended argument with Clement Greenberg and his formalist modernism. With the appearing relationships of the empirical and intelligible, or rather the visual and invisible, the roles of form and seeing as constitutive elements of art were challenged—in accordance with contemporary theory of perception. For the sake of completeness it should be noted that Robert Morris went one step further with a view of the self-experiences of the viewer—what is known today as the phenomenological approach to Minimal Art—and showed with his works, such as his *L-Beams*, referring back to Maurice Merleau-Ponty, that a form can be understood only as gestalt in space-situation-body-relations[53]—Greenberg himself modified formalism in 1967.[54]

Due to these events, in particular relating the Minimalist objects to numerical orders, Judd, and even more so Morris, were described by Burnham as precursors of a systems aesthetic, which he considered paradigmatic with a view to the technological situation; it started with Morris when he brought forms like in *Permutation* (1967) gradually in changing relations,[55] while for Judd's *Progressions* he declared: "Here sets, defined as numerical values, have nothing to do with dimension or finite proportion generated through Euclidean space perception, but transcend the intuitive-concrete to become extensions of pure process and transformation." He continues: "Sculpture becomes 'thingified' by means which cannot be perceived except through the rules for ordering finite or infinite sets of abstract points in a given continuum."[56] Sculpture would mirror a development in modern geometry, which has left (according to Oswald Spengler) the area of visual and empirical and measurable objects behind, and acts now with mathematical functions; thus "Object sculpture," following

50 Ibid., p. 153.
51 Ibid., pp. 204–17, 236–40.
52 Ibid., pp. 135–36.
53 Ibid., pp. 166–71.
54 See Clement Greenberg, "Complaints of an Art Critic," *Artforum* (October 1967), pp. 38–39.
55 See Burnham, "Systems Esthetics," 1968, p. 32.
56 Burnham, *Beyond Modern Sculpture*, 1975, p. 147.

Burnham, shows "that the mathematical model can no longer solve the iconic problems of sculpture."[57] There was a harsh replica by Judd—we will get back to this at the end.

Here, it is important to note that while Judd takes actions against the identification of the intelligible part or rather the mathematical connotation, LeWitt made the tension the content of his work. In his *Serial Project #1 (ABCD)* (1966) he played with it and carries the relativization of form to extremes, which now could be shaped arbitrarily to some degree—as long as the generative rule, here a linguistic-combinatorial one, could be reconstructed.

At the same time, Burnham made out a discrepancy in Judd's *Progressions* with a view to the numerical determination of the objects and their impression and declared with it an inextricable entanglement of the determinants of sculpture: "More than simply an art object's list structure, Judd included phenomenal qualities which would have never shown up in a fabricator's plans, but which proved necessary for the 'seeing' of the object."[58] Actually, the alleged sparse, geometrical objects offer quite a few sensual dimensions regarding their chromaticity, materiality, and lighting conditions, and in that way they would be more than a "list-structure"—which is what programmers call it, namely a listing of those properties which are required for the recreation of a physical object.[59]

Computer sculptors Csuri and Mallary, who had presumably to face up to the technical challenges, could have profited from this discourse. This affects more than the proportion between work and viewer—as a life-sized vertical *Quad III* evokes an anthropomorphism. When the role of form was questioned, the computer sculptors at the same time exposed the potential of the computer within the process of form-finding: in a combinatorial manner as a variant-machine and in a cybernetic manner as a decision-machine. Like the objects of Minimal Art, the computer sculptures were not built for a reception or illustration of its mathematical bases. The latter were elaborated in such a way that they hardly could be identified by a common viewer. The curved forms of *Numeric Milling* are based on Bessel functions—the canonical solutions of Bessel's differential equations[60]—which are of media-technological interest because they find application in calculating how electrical waves propagate in wires.[61] However, in art and design they were not used to my knowledge. Nevertheless, on this level *Numeric Milling* refers to the development of procedures for generating curved surfaces with smooth transitions in mathematics. Such surfaces, which were researched and advertised by General Motors Research Laboratories, were of importance, for instance, for the bodywork of the automobile industry. Thus, the computer sculptures—particularly also the biomorphically appearing one of Mallary—touch on the traditional dualism of geometric and organic forms. What kind of form a given one is, could no longer be determined "superficially" in the 1960s, but only via its manner of origin; Donald Judd could have profited from this insight, because he showed—despite his familiarity with

57 Ibid.
58 Burnham, "Systems Esthetics," 1968, p. 32.
59 Ibid.
60 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, pp. 1297–98.
61 See Paul Schafheitlin, *Die Theorie der Besselschen Funktion* (Berlin/Leipzig: Teubner, 1908), pp. 2–3.

mathematical geometries—a dualistic understanding of form.[62] It seems paradoxical, since Judd's works provide an impression and even identification of mathematics, whereas computer sculptures disable the identification. Finally, computer sculptures like *Numeric Milling* indicate that in the 1960s knowledge and practices of the working world were picked up and applied in the arts. The (mathematical) modeling of surfaces was one thing, but their technical realization quite another—even when both could be entangled in computer production systems.

Mechanization/Automatization

For his work with computer sculpture Charles Csuri was in the right place: he was an academic in Ohio, where the Cincinnati Milling Machine Company operated, and with which he cooperated around 1968.[63] An objective of the use of such machines was to automatize production in an economic sense, reducing primarily manual work, which had been emphatically sought since the 1950s.[64] This happened in the "navigable water" of cybernetics, which was known by the computer sculptors,[65] and in which automatization possessed not inconsiderable significance[66]—Norbert Wiener was called the father of modern cybernetics and the "Father of Automation."[67] Correspondingly, in 1952 an Automatically Programmed Tool System (ATP system) was presented in *Scientific American* as an innovation, which as an analog-digital milling machine system for tools not only proceeded the production process automatically, but also controlled it with "[f]eedback control."[68] Such automation technology makes evident that automatization in a technical sense has to be distinguished in different grades. Under these circumstances one could say that Mallary was engaged in a semi-automation (*Quad III*) and Csuri strived for a complete automation (*Numeric Milling*). Because the functionality of the programming language, which was applied in Automatically Programmed Tool systems, had been not adequate for his artistic purposes, Csuri developed his own procedures.[69]

Mechanization and automatization can be made out—in different ways—also in Minimal and Conceptual Art as well as Serial Art. Arguments were made on the level of methods and objects, which happened in particular in the context of a systems discourse in which,

62 See Rottmann, *Gestaltete Mathematik*, 2020, pp. 29, 51–55.
63 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, p. 1298.
64 See William Pease, "An Automatic Machine Tool," *Scientific American* (September 1952), pp. 101–15, p. 105.
65 See Mallary, "Computer Sculpture," 1969, p. 29.
66 See Norbert Wiener, *Cybernetics or Control and Communication in the Animal and the Machine*, 2nd edition, 4th printing (Cambridge, MA: MIT Press, [1948] 1985), p. 39.
67 Anonymous, "Dr. Norbert Wiener Dead at 69: Known as Father of Automation," *The New York Times*, March 19, 1964, p. 1.
68 Pease, "An Automatic Machine Tool," 1952, p. 101.
69 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, pp. 1297–98.

among other things, work with numbers and rules was understood as systemic.[70] Accordingly, Minimal Art was characterized in the second half of the 1960s not only by industrial materials like steel, aluminum, acrylic or mirror glass, but also by "machine production"—as art historian Jutta Held has analyzed.[71] With fabrication, the artworks changed from the early ones with "traces of workmanship" to "precisely worked, standardized articles."[72] What was done to realize neutrality, for example by erasing the personal handwriting, as was rightly criticized, resulted in the opposite, because now references to industrial or social conditions of production existed. The applied "mathematical rules," following Held, would have been taken "out of the technical world" and "reproduced" by the artists, the "alleged primary shapes" (*Urformen*) are "mediated by recent industrial products" and the "normalized boxes" would mirror "the automatic way of production."[73]

With the use of commercial, technical machines, especially the self-acting ones like the automaton, a certain automatization happened—here understood as a process, which runs totally or partly without the participation of a human being. The debate was not only held on automation technology in the narrow sense. Robert Morris, for instance, attested to Minimal Art another kind of automation, which "precludes any 'arranging' of parts": "The 'how' of making was automated by accepting the method of forming necessary to rectilinear things."[74] For Morris, this practice fits in a system-based art, which his broad conception of "automation" rests on. So "many 20th-century artists"[75] as well as Renaissance sculptor Donatello would have in common, as Morris quite understandably explained, "that some part of the systematic making process has been automated."[76] In these cases, "the artist has stepped aside for more of the world to enter into the art," and at the same time external determinants could unfold their effects within the forming process.[77] Morris offers only a few artists (such as Jasper Johns, Frank Stella, John Cage, and Jackson Pollock), but not LeWitt, who will be addressed here. In a characterization of his Conceptual Art, LeWitt explained that after choosing the formal means, the application of an "idea,"[78] for example

70 See Michael Rottmann, "Kalkulierte Innovationen: Zur Kritik der Systematisierung von Entwurfs- und Innovationsprozessen in der Kunst um 1960," in Claudia Mareis and Rottmann, *Entwerfen mit System*, Studienhefte Problemorientiertes Design, no. 10, ed. Jesko Fezer, Oliver Gemballa, and Matthias Görlich (Hamburg: Adocs, 2020), pp. 123–221.

71 See Jutta Held, "Minimal Art – Eine amerikanische Ideologie," in *Minimal Art: Eine kritische Retrospektive*, ed. Gregor Stemmrich (Basel/Dresden: Verlag der Kunst, 1995), pp. 444–70, here pp. 446–47. Translation by the author.

72 Ibid., pp. 446–47. Translation by the author.

73 Ibid., pp. 459–61. Translation by the author.

74 See Robert Morris, "Some Notes on the Phenomenology of Making: The Search for the Motivated," *Artforum* 8, no. 8 (April 1970), pp. 62–66, here p. 66.

75 Ibid., p. 65.

76 Ibid.

77 Ibid.

78 LeWitt used "idea" and "system" synonymously. See Rottmann, *Gestaltete Mathematik*, 2020, pp. 249–53.

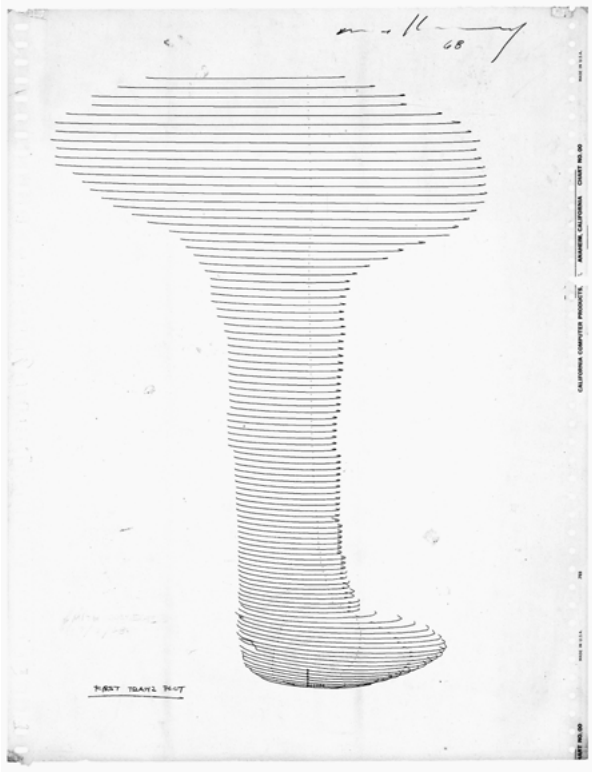
a system (of rules) implies that: "The process is mechanical."[79] His machine metaphor became famous: "The idea becomes a machine that makes the art."[80] As I have argued elsewhere, LeWitt, as well as Mel Bochner, partly automatized their processes in their Serial Art by working with matrixes of mathematics in a generative manner, because these diagrams operated on paper as "symbolic machines."[81] One can also find this notion, which is bound to "rule-media" as I put it,[82] in LeWitt's understanding of text as a kind of a flow chart, which could function as "an operational diagram to automate art"—the artist exemplified this through his programmatic *Sentences on Conceptual Art* (1969).[83]

It becomes apparent that in Serial and Conceptual Art alternative mechanizations and automatizations were declared and pursued. Such practices were by no means only imitative or assertive. Rather, they have to be considered explorative and reflexive; they addressed internal art categories like the idea of the artist genius and were targeted against modernism. As Morris explained: "However it is employed, the automation serves to remove taste and the personal touch by co-opting forces, images, processes, to replace a step formerly taken in a directing or deciding way by the artist."[84] Other than écriture *automatique*, the automatism of Surrealism, which was used to activate and explore unknown areas (of the unconsciousness)—a procedure which stimulates the artist by turning off the control of consciousness, but keeps her/him determinative in the end—with technical-machinic automatization, parts of the creative process were handed over to overcome the restrictions of the (conscious) self.[85] They were also used with a view to addressing the cultural imprint, especially to turn off the personal "biases," which is something Csuri mentioned for computer work.[86] Morris talked about a "controlled lack of control."[87] He made a good point when he accentuated that with automation the arbitrary in art would just not diminish, because now forces would be effective, which are "beyond his [the artist's] total personal control."[88]

2D/3D and In Between

One technical problem in the making of computer sculpture in the 1960s was the entire representation of a three-dimensional object with a digital model, as Robert Mallary has

79 See Sol LeWitt, "Sentences on Conceptual Art," *0–9*, no. 5 (January 1969), pp. 3–5.
80 Sol LeWitt, "Paragraphs on Conceptual Art," *Artforum* 5, no. 10 (1967), p. 79–83, here p. 80.
81 See Michael Rottmann, "Checking Creativity: Machines, Media and Mathematics in Early Computer, Serial and Conceptual Art," *Proceedings: Conference EVA Copenhagen 2018: Politics of the Machine—Art and After*, Aalborg University Copenhagen, May 15–17, 2018, pp. 1–10, here p. 5–6, doi: 10.14236/ewic/EVAC18.2.
82 See ibid., p. 6.
83 Quoted in Rottmann, *Gestaltete Mathematik*, 2020, p. 278.
84 Morris, "Some Notes on the Phenomenology of Making," 1970, p. 65.
85 For Bochner, see Rottmann, *Gestaltete Mathematik*, 2020, p. 289.
86 See Csuri and Shaffer, "Art, Computer and Mathematics," 1968, p. 1295.
87 Morris, "Some Notes on the Phenomenology of Making," 1970, pp. 65–66.
88 Ibid., p. 66.



5 Robert Mallary, plotter drawing, 1968, computer-generated Drawing with *TRAN 2*, ink on plotter paper, IBM 1130, plotter, ca. 30 × 40 cm.

explicated.[89] It can be assumed that computer programs were oriented to existing output devices like the screen and plotter, which had been designed for two-dimensional displaying. If three-dimensional objects were displayed on its surfaces in an illusionistic manner, their representations did not need to be identical with those of an actual three-dimensional object. Considering this technical condition, it becomes comprehensible why sculpture was thought and practiced—as discussed for *Quad III*—as a compound of two-dimensional elements. A starting point was the older idea of "multi-planar image synthesis,"[90] the description and creation of three-dimensional forms with two-dimensional ones—in *Quad III* stapled disks—in the way of a contour map (fig. 5). The displaying and making of three-dimensional forms could be stimulated by mathematics, which has a long tradition of representing (geometrical) objects (of higher dimensions) and methods of projection and intersection, as well as by industry, in which such concepts must be developed for milling,

89 Mallary, "Computer Sculpture," 1969, p. 30.

90 See Robert Mallary, Interview, in *Artist and Computer*, ed. Ruth Leavitt (New York: Harmony Books, 1976), pp. 4–8.

punching, or casting three-dimensional forms (e.g., milling machines with three axes).[91] From this viewpoint, computer sculpture—plastic procedures included—could be more interesting than computer graphics for industry and its development of mostly three-dimensional products.

The subject of dimensionality was also an issue for Greenberg and for Minimal, Serial, and Conceptual Art, as I have shown elsewhere, in respect to the theory of sculpture and the aesthetics of production: the relationship of two- and three-dimensionality was an ingredient, because these art forms operated with transforming media, for instance a draft into an object, and they related both types of dimensionality, in presentations of multipart works for example.[92] One could talk about pendulousnesses. Painting as a starting and reference point was increasingly made and understood as object-like (Johns, LeWitt, Judd, Stella), thus helping to reach object art; the same goes for Mallary: "I conceive of an image as a monolith, an actual object in an actual place, aggressive in the factuality of its physical and sculptural attributes of surface, shape and substance."[93] He was interested in the interspace between painting and sculpture—the "impasto of painting" could "preserve[] its pictorial 'skin,'" but also allows for being "transformed into sculpture"—seeing in himself "more a painter than a sculptor."[94] Many of the mentioned artists continued a kind of drawing and/or turned back to graphics later; LeWitt even pursued a maximal two-dimensionality with his *Wall Drawings*.[95] So, artists like Judd and LeWitt not only attacked modernism with a rhetoric of change, for example with their terms "Specific Objects" (Judd) and "Structures" (LeWitt), but also with an interdimensionality (*Zwischendimensionalität*), as I call it, which can be ascribed to their painting-originated space-expanding objects in the early 1960s, like the already mentioned *Wall Structure* (1963) or Judd's *Relief* (1961).[96] These objects are in-betweens and can be located between painting and sculpture, which are commonly described as two- and three-dimensional media; actually, Greenberg argued that media specificity is also determined by dimension number—he declared painting as two-dimensional, sculpture as three-dimensional. Minimal and Serial Art were busy with the relation of draft and artwork and their discrepancy.[97] Moreover, the object's three-dimensionality was an important ingredient in the discourse of image and sculpture of the 1960s (in Minimal Art)—aspects of it had been already addressed (*L-Beams*): a specific body-relatedness and a critique of its (kinaesthetic) experience (Krauss, Morris) as well as the discrepancy between

91 See Jens Schröter, *3D: History, Theory, and Aesthetics of the Transplane Image* (New York/London/New Delhi/Sydney: Bloomsbury, 2014).

92 See Rottmann, *Gestaltete Mathematik*, 2020, pp. 122–25. Dimensionalites are here understood in an art-historical sense, not in a strictly mathematical one (a physical, flat surface is actually not a 2D object).

93 Robert Mallary, Statement, in *Sixteen Americans*, ed. Dorothy Miller, exh. cat. Museum of Modern Art (New York: Museum of Modern Art New York, 1959), pp. 47–51, here p. 47.

94 Ibid.

95 See Rottmann, *Gestaltete Mathematik*, 2020, p. 295.

96 Ibid., p. 123.

97 For Stella and Judd, see Rottmann, "Checking Creativity," 2018, p. 7.

system and object. While in the context of a phenomenological approach, the object-viewer relation was also treated.[98] Therefore, Robert Morris suggested that Minimal Art "attempted to mediate between the notational knowledge of flat concerns (systems, the diagrammatic, the logically constructed and placed, the preconceived) and the concerns of objects (the relativity of perception in depth)."[99] In contrast, the artistic process and media of draft-like drawing were exposed, aiming not only against formalism, but also against capitalism and materialism. LeWitt explained that a "doodled drawing" with the basic idea is as important as a "three-dimensional structure."[100] And elsewhere he wrote: "I wasn't showing a formal sculpture, I was showing a thought process."[101] The well-known "dematerialization of art" was diagnosed. It is quite understandable that the transformation of reality into information—and this can be applied to today's debate about social media—was criticized (by Les Levine) because "direct, corporal experiences" would be replaced by "second-hand mental experiences."[102]

A Broader Perspective and Conclusions

Computer sculpture on the one hand, and Minimal, Serial, and Conceptual Art on the other hand, have considerable intersections concerning internal themes of art—in terms of the discourses of form, image, and sculpture. They clearly show parallels with a view to mathematization, mechanization, and automatization as well as a 2D/3D debate. The historical context in the United States, which was built in particular by cybernetics, systems theory, computerization, and digitalization as well as the Cold War, gives us a framework for further explanations. I want to argue that both art fields have to be thought of together. The presented events in Minimal, Serial, and Conceptual Art can be made out as a parallel history of early digital art. Accordingly, Conceptual Art and art and technology were determined in their relation as "constituents of larger social transformations from the machine age of industrial society to the so-called information age of post-industrial society."[103] Such art movements, which can be linked to digital art and its subjects and its (information) technology, which are—like LeWitts's Conceptual Art—more or less explicitly thematized and reflected, but without commercial or built (digital) machines, I want to call "co-digital art." Their intersection—for just that reason they are named here as (digital) machine arts—is still the current question, how certain artforms behave with technology and the mechanization of art and society, in particular which man-machine relationship they represent and which role they assign to the body.[104] This all is the more true since mechanization and the

98 For a reconstruction, see Rottmann, *Gestaltete Mathematik*, 2020, pp. 165–77.
99 Robert Morris, "Aligned with Nazca," *Artforum* 14, no. 2 (October 1975), pp. 26–39, here p. 39.
100 Here quoted in Rottmann, *Gestaltete Mathematik*, 2020, p. 294.
101 Quoted in ibid., p. 297.
102 See Shanken, "Art in the Information Age," 2002, p. 436.
103 Although he does not differentiate Conceptual Art, see ibid., p. 433.
104 See, e.g., Charlie Gere, *Digital Culture* (London: Reaktion Books, 2002), pp. 75–149.

promotion of interdisciplinary cooperations, for instance in art and technology movements like Experiments in Art & Technology (E.A.T.), were driven forward strategically on the part of industry and politics to serve an "instrumental creativity" in the course of economic and hegemonial competition.[105]

The discussed representatives of computer sculpture have to be described as technophile, if not techno-euphoric and, albeit it sounds chlichéd, assertive by trend. They even seem to have the belief in progress, e.g., when they praised (future) possibilities of computer work. This is also indicated by Csuri's first project grant, which was part of a National Science Foundation program to show the usefulness of computers, especially in art and design.[106] When the computer sculptors treated interaction and production—in particular of art—in the context of tackling the man-machine relationship they did it pragmatically and outcome-orientedly. But Minimal Art also behaved assertive toward technological and industrial society. This was explained by competition with Europe and a related stocktaking.[107] When a "mechanization of the artistic production," with an "equalizing technical working process" and a generating of non-relational artworks with numerical schemes, which were considered as objective and naturally inevitable, should help to reduce the belief in the artists' special position prevailing in Europe (especially since Kant), as Jutta Held has argued, this activity has to be understood as being based on the "American ideology of egality."[108] Finally, the theories of Minimal Art would be infiltrated by "American ideology," the belief in science and technological rationality, as well as in the superiority of American civilization due to technical leadership, and this would determine the forms of their "products."[109] Taking a subordinate role to technology would no longer be experienced as alienation, but as a natural historical development—Held also recalled Andy Warhol's statement "I want to be a machine."[110]

The situation turned out to be rather ambivalent. The aesthetics and politics of machination and automatization were also criticized, foremost in Minimal, Serial, and Conceptual Art. To say it paradoxically: this was done with machines against machines and with automatization against automatization—by the way, the different notions of the terms "machine" and "automatization" have so far been used because of a historical and disciplinary variance, which I am pursuing in my current research project "Automated Innovations." When Donald Judd, for instance, pursued with his numerical schemes a "one-shot" production,[111] this can be interpreted as a reaction against cybernetic feedback; together with Frank Stella,

105 See Claudia Mareis, "Kreatives Problemlösen: Entwurfsdebatten im Kontext von Designmethodologie und Kreativitätsforschung," in Mareis and Rottmann, *Entwerfen mit System*, 2020, pp. 25–120. Translation by the author.

106 See Freedman, "Oral History Interview," 1989, n.p.

107 See Held, "Minimal Art," 1995, pp. 458–59.

108 Ibid., pp. 457, 464–65. Translation by the author.

109 Ibid., pp. 458–59. Translation by the author.

110 Ibid., pp. 460–61. Translation by the author. See Gene Swenson, "What Is Pop Art? Answers from 8 Painters, Part I," *Art News* 62, no. 7 (November 1963), pp. 24–27, 60–63, here p. 26.

111 Quoted in Rottmann, *Gestaltete Mathematik*, 2020, p. 208.

who worked with systematic/automated draft methods, he debated the (fundamental) limits of such methods (in art and beyond).[112] The loss of control, intrinsic to the work with (self-chosen or created) machines or systems and related automations, was exercised and demonstrated by the artists; "control" was not least a key term in the discourse of creativity, which was also exploited politically. With the help of an aesthetics of surprise, artists like LeWitt brought home their thoughts about the moment of a fundamental uncontrollability in so-called rational, system-based and automatized processes and their limitations.[113] In Serial and Conceptual Art, the introduced work with machines and automatization can be understood, especially because it happened without commercial machines, not only as a critique of cultural production, but also of a social and economical one and its effects. We have to consider the fact that not only was production, as well as administration, automatized in the US, in particular for information processing. Jack Burnham called it the "automated state" in 1968, explaining that "power resides less in the control of the traditional symbols of wealth than in information."[114] Against this background, i.e., the development of an information society and a digital culture, LeWitt's activities were related to information technology.[115] It was quite rightly indicated that his concept of machine, which suggests mass production, is contradictory; the mathematical systems he used, like in *Incomplete Open Cubes* (1977), are anachronistic, inconsistent, and idiosyncratic (which LeWitt himself stressed again and again), thus his machines do not allow faultless, identical reproduction.[116] In the end, a gap revealed itself between predicted future possibilities and a technological possible reality. Until today, not everything can be automatized; this goes for the course of automated processes as well as for their necessary infrastructures, which must be installed before. When LeWitt characterized Conceptual Art as machine-like, which implicates a proximity to technology, and at the same time he warned that the idea could fall behind, a dilemma of the relationship of art and technology was called out.[117] An art that orients itself to technology could be criticized not only as "dominated by the materiality and spectacle of mechanical apparatus," as it was expressed for the art-and-technology movement, but also, when tending to materialization and work- and ware-likeness, that it could lose its anti-capitalist line of attack, and especially, with a view to Conceptual Art, its primacy of the idea.[118] Furthermore, negative aspects of technology could become part of art—for instance the development and use in the military complex (Vietnam War) or its instrumentalization in Cold War (space race).[119] Robert Smithson wrote very clearly: "To celebrate the power of technology through art strikes me as a sad parody of NASA. I do not share the confidence

112 See Rottmann, "Kalkulierte Innovationen," pp. 148–53.
113 Ibid., p. 185.
114 Burnham, "Systems Esthetics," 1968, p. 31.
115 See, e.g., Sabeth Buchmann, *Denken gegen das Denken* (Berlin: b_books, 2007).
116 See Rottmann, *Gestaltete Mathematik*, 2020, p. 342.
117 See Shanken, "Art in the Information Age," 2002, p. 436.
118 Ibid.
119 Ibid.

of the astronauts. The rationalism and logic of the engineer is too self-assured. Art aping science turns into a cultural malaise."[120]

Donald Judd also pleads for a separation of art and science, although he was academically trained and well informed about scientific issues, in particular those of mathematics.[121] He expressed his displeasure about Jack Burnham—to come back to it—who related the innovation of sculpture to the altered relationship of human and technology, in which objects would have regained their autonomy. Judd criticized this "sort of sloppy correlations of such highly different activities as science and arts" and Burnham's conception of history as thoughtless and deterministic.[122] Similarly, he was displeased by Burnham's prognosis, who saw only two ways for sculpture: "it can be fashioned as a reaction against technology or as an extension of technological methodology."[123] Certainly, one could discuss Burnham's and Judd's arguments, but the relationship of art and technology has become an issue with growing importance for sculpture in the (post-)digital age.

120 Robert Smithson, letter to Gyorgy Kepes (1969), in *Robert Smithson: The Collected Writings*, ed. Jack Flam (Berkeley/Los Angeles/London: University of California Press, 1996), p. 360.

121 See Rottmann, *Gestaltete Mathematik*, 2020, pp. 335–36.

122 Donald Judd, "Complaints: Part I," *Studio International* 182 (April 1969): 182–88, here 184.

123 Ibid.