

Cosmopolitics and Virtual Environments in Architectural Design Studio Teaching: Collaborative Computer-Aided Strategies and Social and Environmental Equity

MARIANNA CHARITONIDOU

Athens School of Fine Arts

Keywords: cosmopolitics, paperless studios, creative collaboration, Virtual Design Studios

The necessity to combine sustainable methods in architectural and urban design and democratization calls for a shift from technical to the socio-technical perspectives within the field of architecture and urbanism, which is related to a need to reshape pedagogical agendas. At the center of the paper is the conviction that this endeavor of combining social and environmental equity in data-driven societies goes hand in hand with the intention of placing emphasis in critical thinking, self-reflection, social awareness, imagination, and activism in architectural education. The necessity to combine sustainable methods in architectural and urban design and democratization calls for a shift from technical to the socio-technical perspectives within the field of architecture and urbanism which is related to a need to reshape pedagogical agendas. At the center of the paper is the conviction that this endeavor of combining social and environmental equity in data-driven societies goes hand in hand with the intention of placing emphasis in critical thinking self-reflection social awareness imagination and activism in architectural education. To shed light on the role of cosmopolitan citizenship in reshaping architectural education the paper examines how “cosmopolitics” as ecology of practices can help us reinvent the relationship between individual subjectivity and collective subjectivity in architectural education. The paper also intends to examine two issues: firstly, the mutation of the status of the architectural artefact because of the fact that the form is generated through the use of digital tools; secondly, the implications of the possibility of real-time data visualisation for the reconceptualization of the notion of spatiality.

INTRODUCTION

The main objective of the paper is to render explicit how digital design tools and hybrid use of software and hardware provide the conditions for more mutable and open-ended generative processes than those provided by conventional methods of architectural design. The distinction between the digital and computation is pivotal for grasping the epistemological mutations that are pinpointed here. The digital refers to a kind of state of being, or a condition, while the computation concerns active

processes¹. Another issue that is examined, in the article, is the interaction between physical, virtual and augmented reality and the real-virtual relationship in the case of augmented reality. All the case studies that are analysed in this article are based on the experimentation with geometry. The reasons for which they have been chosen to be examined are mainly two: firstly, they exemplify an ontological shift of the design process; secondly, they illustrate a reinvention of the established hierarchies of the design process. A common parameter of the case studies that are examined in this article is their ambition to invert the role between the architectural profession and architectural academia.

THE EMERGENCE OF THE “PAPERLESS STUDIOS” AT COLUMBIA UNIVERSITY’S GRADUATE SCHOOL OF ARCHITECTURE, PLANNING AND PRESERVATION

The “paperless studios” refer to the establishment of a new pedagogical agenda concerning the teaching of design studios at the Graduate School of Architecture, Planning and Preservation (GSAPP) at Columbia University during the mid-1990s at the initiative of Bernard Tschumi who was then dean at the aforementioned institution. As it becomes explicit in Bernard Tschumi’s article entitled “The School’s New Computing Facilities”, published in *Newsline* in 1994, the main aspiration of the so-called “paperless studios” was the creation of circumstances that would permit schools of architecture to acquire a more protagonist concerning their relationship with the existing conditions in the profession². According to Tschumi, this would become possible through the creation of new conditions of architectural production regarding the design process and the generation of forms, but also their construction and the relationship between the design process and the construction. Tschumi was convinced that these new conditions would have an important impact on the way architectural design practices function. Similarly, Mark Goulthorpe, Mark Burry and Grant Dunlop remark, in “The Bordering of University and Practice”, that thanks to the use of digital design tools “practice becomes reliant on the universities to solve design methodology problems”³.

An aspect of the “paperless studios” and especially of Hani Rashid’s studio is the intensification of the role of augmented reality and its contribution to the transformation of the experience of spatiality. The distinction between augmented reality and



Figure 1. Cover of *Newsline* (January/February 1995).

objects, while in the case of augmented virtuality users interact with the virtual environment within a context characterised by the fusion of the virtual and physical objects. In other words, in the case of augmented reality, virtual and physical objects are displayed seamlessly. As Xiangyu Wang notes, in “Augmented Reality in Architecture and Design: Potentials and Challenges for Application”, “[a]ugmented [r]eality [...] is a technology or an environment where the additional information generated by a computer is inserted into the user’s view of real world scene”⁴. Both virtual and augmented reality extend the sensorial environment of an individual by mediating reality through technology.

Bernard Tschumi’s aspirations regarding the “paperless studios” went far beyond a technophile vision. They were based on the intention to embrace “a new attitude toward programs and the production of events, so as to reconfigure and to provide a rich texture of experience start will redefine architecture and urban life”⁵. Despite the fact that at the beginning the “paperless studios” were only two out of twelve or thirteen design studios at Columbia University’s GSAPP, their impact on architecture’s epistemological reorientation was significant. They marked a turning point concerning the dissemination of digital tools in architectural education and profession. Apart from Stan Allen and Greg Lynn, who taught the first two “paperless studios”, other educators involved in them were Jesse Reiser, Hani Rashid, Keller Easterling, Scott Marble, Richard Plunz and Laurie Hawkinson. The central aspiration of the “paperless studios” was to provide a terrain of experimentation rendering explicit that the conception

augmented virtuality is of great significance in order to comprehend what is at stake in the projects under study in this article. In the case of augmented reality, users interact with physical

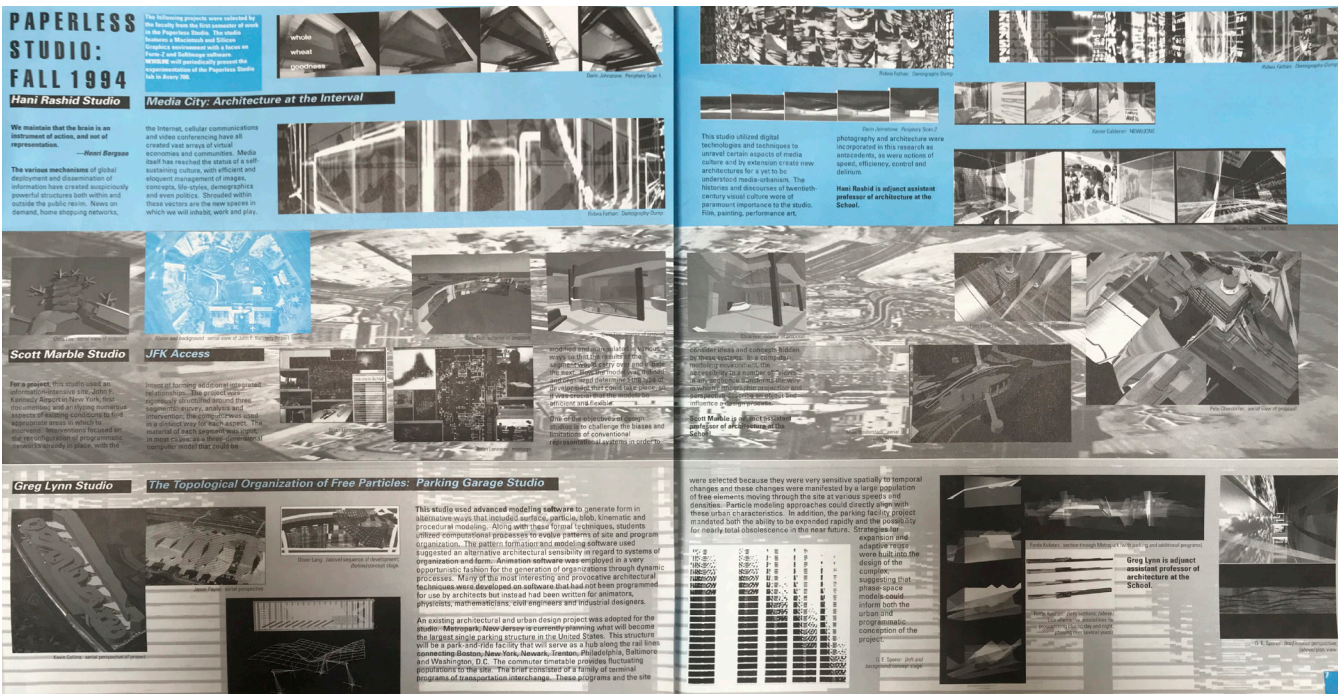


Figure 2. Hani Rashid, Scott Marble, Greg Lynn, “1995. Paperless Studio: Fall 1994”, *Newsline*, (1995): 6-7.

of architectural design processes according to its conventional phases and categories should be challenged (Figure 1, Figure 2).

Tschumi's agenda as dean of Columbia University's GSAPP was based on his conviction that schools of architecture should establish new strategies concerning the transmission of knowledge and skills. He believed that these new strategies should aim to render architects "instrumental in the construction of the new computerized technologies that are already transforming building and design processes". The very force of his vision lies in the way he related the emergence of "a new social conscience" after the 1968 protests to the necessity to take distance from "a laissez-faire acceptance of today's design conditions". He was convinced that architects should "design new conditions" and go "[b]eyond the construction of technology". He related the creation of these new conditions for architecture to the emergence of "new attitudes toward the activities that take place in architectural spaces"⁶. The main objective of the "paperless studios" was to incorporate the emerging digital technologies. The first "paperless studios" were based on the use of Macintosh computers and FormZ, a Boolean-driven solids software, and three or four Silicon Graphics machines, which were running Softimage. Maya was introduced to the "paperless studios" later than FormZ. The "paperless studios" addressed to third year students and were incorporated the use of Alias and Softimage, two software that were also used in Hollywood at the time. The software, instead of being only a rendering tool, informed and transformed the design process⁷.

Hani Rashid's studio for the first semester of the Paperless Studio at GSAPP Columbia University was entitled "Media City: Architecture at the Interval", while Greg Lynn's Studio during the fall 1994 was entitled "The Topological Organization of Free Particles: Parking Garage Studio"⁸. Hani Rashid's paperless studio was focused on the production of video installation pieces. Later, he introduced interactivity to these virtual reality experiments using VRML. The use of animation software that has been at a first place produced to be used by animators, physicists, mathematicians, civil engineers and industrial designers, served to generate organizations through dynamic processes. Greg Lynn's paperless studio focused on an existing architectural and urban design project – Metropark in New Jersey – that had been conceived as one of the largest single parking structures in the U.S. along the rail lines connecting Boston, New York, Newark, Trenton, Philadelphia, Baltimore and Washington, D.C. Among the students were Kevin Collins, Jason Payne and Oliver Lang. According to what Bernard Tschumi claims in "The Making of a Generation: How the Paperless Studios Came About", Scott Marble used fly-through, Stan Allen used datascares, Hani Rashid did a lot of collage and Greg Lynn introduced the experimentation with fluid mechanics⁹. Tschumi, in the same text, poses the following question: "to what extent did computer enable architecture to develop new concepts?"¹⁰ He also reflects upon how the digital tool we use is more than a formal device that has a fantastic ability to be translated in construction terms?¹¹

CREATIVE COLLABORATION IN VIRTUAL DESIGN STUDIOS

At the centre of this paper is the notion of creative collaboration, and the significance of shaping tools and methods allowing schools of architecture to incorporate collaborative learning conduct in Virtual Design Studios (VDS). As Sohyun Park highlights, "[i]n design disciplines, studios provide an important environment for collaborative learning"¹². Park also remarks that "design knowledge is difficult to externalize and is more tacit"¹³. A question that became central in the debates around online architectural education during the current pandemic is the role of interaction in VDS. Because of the necessity to embrace the possibilities of VDS during COVID-19 pandemic, an indispensable epistemological and methodological shift concerning the education of VDS took place. The role of collaborative learning in VDS, for obvious reasons, became more central during COVID-19 pandemic. The necessity to shape methods based on the use of VDS provoked a proliferation of publications and debates on the topic. During a short period, an indispensable epistemological and methodological shift concerning the education of architectural design took place. However, there are several articles and books that appeared in the early 20s that also aimed to address the use of VDS. Among them I could refer to the volume *Understanding Virtual Design Studios* edited by Mary Lou Maher, Simeon J. Simoff, Anna Cicognani¹⁴, and to the research of Seung Wan Hong Inha, Ahmed El Antably and Yehuda E Kalay on the capacity of multi-user virtual environment to enhance creative collaboration¹⁵. Instead of investigating this question theoretically, Hong, El Antably and Kalay aimed to examine it empirically. More specifically, they compared Multi-User Virtual Environments (MUVES) with online sketching media. They paid special attention to the ways in which "[c]ollaboration [can function as] [...] enabling force"¹⁶, placing particular emphasis on collaboration as a "complex, interpersonal synergetic process"¹⁷. Hong, El Antably and Kalay, in their article entitled *Architectural Design Creativity in Multi-User Virtual Environment: A Comparative Analysis between Remote Collaboration Media* drew upon Donald Schön's analysis in *The Reflective Practitioner: How Professionals Think in Action*¹⁸ in order to render explicit how "collaboration can promote creativity by reflective feedbacks"¹⁹.

Aminreza Iranmanesh and Zeynep Onur, in "Generation gap, learning from the experience of compulsory remote architectural design studio", highlight the impact of the work of Schön on theory of architectural design studio²⁰. More specifically, they shed light on the role of "reflection in action"²¹ and "learning by doing"²² in Schön's work, and highlight that Schön argues that "design studio provided a platform in which the learner could exercise *learning by doing* while interacting with others and experiencing *reflection in action*"²³. They also underscore that, according to Donald Schön and Glenn Wiggins, "the material medium (pen, paper, and models) through which the reflective interaction takes place is a critical aspect of the architectural design studio"²⁴. Aminreza Iranmanesh and Zeynep Onur identify

the following three questions as core questions related to the epistemological shift in architectural design education due to the necessity during COVID-19 pandemic to explore strategies of teaching architectural design studio virtually: “What is the nature of distance education regarding architectural studios? What are suitable tools and mediums? What should the learning outcomes be, and how do these compare with the physical design studio?”²⁵

Hong, ElAntably, Kalay remark, in “Architectural Design Creativity in Multi-User Virtual Environment: A Comparative Analysis between Remote Collaboration Media”, that “[a] successful MUVE is thus a digital place that replaces physical attributes in conventional environments with shared digital objects and actions with co-presence”²⁶. In the empirical part of the aforementioned paper, they focused their analysis on Second Life (SL), which is a commonly used MUVE platform. In the case of SL, users log in to the virtual environment as anthropomorphic avatars and can “command their avatars to perform gestures, communicating a limited vocabulary of body language”²⁷. Hong, El Antably and Kalay, compare the potentials of SL with those of Group Board (GB) – an online blackboard environment. Seung Wan Hong Inha, Ahmed El Antably and Yehuda E Kalay used Consensual Assessment Technique (CAT) in order to assess the role of creativity in these two cases.

SL was also analysed by Shantanu Tilak, Michael Glassman and Irina Kuznetcova, in “Multi-User Virtual Environments (MUVEs) as Alternative Lifeworlds: Transformative Learning in Cyberspace”²⁸. Tilak, Glassman and Kuznetcova argue that SL “facilitated more critical reflection and transformative learning trajectories as compared to direct instruction frameworks”²⁹. Stephan Sonnenburg, in “Creativity in Communication: A Theoretical Framework for Collaborative Product Creation”, refers to the eight phases of the creative process in collaboration: problem finding, problem acceptance, preparation, incubation, illumination, verification, modification, solution³⁰. In the aforementioned article, Sonnenburg examines the “driving force for collaborative creativity”³¹. He draws a distinction between “face-to-face interaction” and “tool-mediated interaction”³².

Nader Gharib and Hamad Mostafa distinguish three types of learning processes in the case of architecture VDS: the one-to-one, the one-to-group and the group-to-group³³. Ken Yocom, Gundula Proksch, Branden Born and Shannon K. Tyman, in their article entitled “The Built Environments Laboratory: An Interdisciplinary Framework for Studio Education in the Planning and Design Disciplines”, analyse the potentials of enhancing collaborative work in education. More specifically, they place particular emphasis on how collaborative teaching contribute to social equity. They also highlight the importance of “team-based and research-oriented approaches”³⁴.

Spyros Vosinakis and Panayiotis Koutsabasis remark, a worth-noting advantage of the Virtual Worlds (VWs) is the fact that they offer to their users the opportunity to “meet and collaborate in shared workplaces”³⁵. Burak Pak, Caroline Newton and Johan Verbeke distinguish VWs in the following four categories: “the real virtual, virtual augmented real, real augmented virtual and fantastic virtual”³⁶. An important advantage of the incorporation of the VWs in online architectural design studio teaching is the fact that, thanks to the use integrated platforms, “the learning community has the chance to see not only the final outcome but also the resources and paradigms that led to it”³⁷.

Ken Yocom, Gundula Proksch, Branden Born and Shannon K. Tyman, in “The Built Environments Laboratory: An Interdisciplinary Framework for Studio Education in the Planning and Design Disciplines”, examine the role of integration in design studio teaching. They understand integration as “the process through which theories and methods from multiple disciplines are explored, evaluated, and tested to develop an approach for analysing a specific problem from multiple perspectives”³⁸.

CONCLUSIONS

The reinvention of the relationship between architectural pedagogy and architectural practice due to the establishment of “paperless studios” and the incorporation of new software and advanced digital technologies in the teaching procedure and design process was accompanied by a transformation of the ontological status of architectural artefacts. Thérèse Tierney analyses this mutation of the ontological status of architectural artefacts in her book entitled *Abstract Space: Beneath the Media Surface*. Tierney explains in which sense the architectural drawings that are produced through the use of digital tools differ ontologically from those that are produced analogically. More specifically, she claims that “[e]volutionary form-generating software had transformed the architecture image into event and performance, either by understanding architecture as the epigenesis of spatial conditions, or by the object being conceptualized as the actualization of built-up potentials”³⁹. In order to better grasp the ontological shift of architectural artefacts due to their production through the use of computation tools, one should bear in mind that “[d]igital architecture objects cannot be said to represent architecture in the same sense that the drawings or models that make up conventional architectural collections do”⁴⁰.

Mario Carpo’s *The Alphabet and the Algorithm* is useful for better grasping the epistemological and ontological shifts related to the questions addressed in this article. Carpo remarks referring to the digital turn of the 1990s that “[t]he new organicist and morphogenetic theories that crossed paths with the mathematical ones [...] would eventually become staples of digital design theory”⁴¹. Carpo considers as very central for this first digital

turn Greg Lynn, especially his *Folds, Bodies & Blobs: Collected Essays*⁴² and *Animate Form*⁴³, and Bernard Cache with his book entitled *Earth Moves: The Furnishing of Territories*, where he develops his reflections around the concept of the “objectile”⁴⁴. Cache’s aforementioned book had an important impact on introducing an ensemble of concepts of Gilles Deleuze’s work, and especially of his reflections in *The Fold: Leibniz and the Baroque*⁴⁵ in architectural debates.

In *The Second Digital Turn: Design Beyond Intelligence*, Carpo draws a distinction between the first and the second digital turn, claiming that the first digital turn was characterised by the invention and interpretation of “a new cultural and technical paradigm [...] [and the creation of] a visual style that defined an epoch and shaped technological change”⁴⁶. One could claim that the second digital turn, which concerns the present state of architecture has to do mostly with the ongoing debates around the role of Big Data, especially in relation to questions concerning the notions of sovereignty, democracy and the public realm, and less with the formal and visual experimentations that were at the centre of the first digital turn. The current state of digital turn in architecture is more oriented towards social aspects, placing particular emphasis on questions concerning the democratisation of data and the issues related to the role of “digital commons”⁴⁷. Within such a context, most of the efforts are concentrated on sharpening the visualisation techniques and on using them in order to transform top-down design strategies into more bottom-up ones.

The second digital turn in architecture to which Mario Carpo refers⁴⁸ is related to the generalised use of “digital twins” in exploring urban policy scenarios. Despite the aspirations of urban scale digital twins to enhance the participation of citizens in the decision-making processes and to incorporate their input to urban planning strategies, the fact that they are based on a limited set of variables and processes should be taken into consideration when we use them in order to take decisions in city scale⁴⁹. Yanni Loukissas and Anita Say Chan criticize “digital universalism”⁵⁰. Their critique is useful for understanding that “digital twins”, despite their potentials, they entail the risks of neglecting the social aspects of urban fabric since they are based on the abstraction of sets of variables and processes.

An ensemble of tendencies that try to incorporate the advantages of big data in the very design processes, in both architecture and urban planning, “share an optimism towards the flexibility offered by technology [...] [and] are based on the conviction that big data offer citizens the possibility to ‘make connections [...] in a more visible way and acquire more insights about the ubiquitous presence of digital and data technologies in the city’⁵¹. A risk that is present in data-driven societies, which are based on the myths of “digital universalism”, is to neglect that all data have complex attachments to place. To avoid this, one should bare in mind the following six principles that are examined by Loukissas in *All Data Are Local: Thinking Critically in a Data-Driven Society*: all

data are local; data have complex attachments to place; data are collected from heterogeneous sources; data and algorithms are inextricably entangled; interfaces recontextualize data; and data are indexes to local knowledge⁵². These remarks concerning a local understanding of data are useful also for comprehending the processes of creative learning in technology-based instruction environments such as VDS.

Acknowledgments



The research project was supported by the Hellenic Foundation for Research and Innovation (H.F.R.I.) under the “3rd Call for H.F.R.I. Research Projects to support Post-Doctoral Researchers” (Project Number: 7833)

ENDNOTES

1. Stan Allen, "The Paperless Studios in Context", in Andrew Goodhouse, ed., *When Is the Digital in Architecture?* (Montreal; Berlin: Canadian Centre for Architecture/Sternberg Press, 2017), 383-404.
2. Marianna Charitonidou, *Architectural Drawings as Investigating Devices Architecture's Changing Scope in the 20th Century* (London; New York: Routledge, 2023).
3. Mark Goulthorpe, Mark Burry, Grant Dunlop, "Aegis Hyposurface©: The Bordering of University and Practice", in *Proceedings of the Twenty First Annual Conference of the Association for Computer-Aided Design in Architecture, ACADIA, 11-14 October 2001* (New York: CUMINCAD, 2001), 345.
4. Xiangyu Wang, "Augmented Reality in Architecture and Design: Potentials and Challenges for Application", *International Journal of Architectural Computing*, 7(2) (2009): 309-326; Wang, Marc Aurel Schnabel, eds., *Mixed Reality in Architecture, Design, and Construction* (Dordrecht: Springer, 2008).
5. Bernard Tschumi, "The School's New Computing Facilities", *Newsline* (1994): 8-9.
6. Ibid.
7. Alfredo Andia, "Integrating Digital Design and Architecture During the Past Three Decades", *Proceedings of the Seventh International Conference on Virtual Systems and Multimedia (VSMM'01)* (Berkeley, California: IEEE Computer Society, 2001), 677-686.
8. Hani Rashid, Scott Marble, Greg Lynn, "Paperless Studio: Fall 1994", *Newsline* (1995): 6-7.
9. Tschumi, "The Making of a Generation: How the Paperless Studios Came About", in Andrew Goodhouse, ed., *When Is the Digital in Architecture?* (Montreal; Berlin: Canadian Centre for Architecture/Sternberg Press, 2017), 415.
10. Ibid., 418.
11. Ibid.
12. Sohyun Park, "Rethinking design studios as an integrative multi-layered collaboration environment", *Journal of Urban Design*, 25(4) (2020): 523-550, doi: <https://doi.org/10.1080/13574809.2020.1734449>
13. Ibid.
14. Mary Lou Maher, Simeon J. Simeoff, Anna Cicognani, eds., *Understanding Virtual Design Studios* (London: Springer-Verlag, 2000).
15. Seung Wan Hong, Ahmed El Antably, Yehuda E Kalay, "Architectural Design Creativity in Multi-User Virtual Environment: A Comparative Analysis between Remote Collaboration Media", *Environment and Planning B: Urban Analytics and City Science*, 46(5) (2019): 826-844, doi: <https://doi.org/10.1177/2399808317733267>
16. Ibid., 827.
17. Ibid.
18. Donald Schön, *The Reflective Practitioner: How Professionals Think in Action* (New York: Basic Books, 1983).
19. Hong, El Antably, Kalay, "Architectural Design Creativity in Multi-User Virtual Environment: A Comparative Analysis between Remote Collaboration Media", 828.
20. Aminreza Iranmanesh, Zeynep Onur, "Generation gap, learning from the experience of compulsory remote architectural design studio", *International Journal of Educational Technology in Higher Education*, 19(40) (2022): 1-19, doi: <https://doi.org/10.1186/s41239-022-00345-7>
21. Ibid.
22. Ibid.
23. Ibid., 5.
24. Ibid; Donald Schön, Glenn Wiggins, "Kinds of seeing and their functions in designing", *Design Studies*, 13(2) (1992): 135-156, doi: [https://doi.org/10.1016/0142-694X\(92\)90268-F](https://doi.org/10.1016/0142-694X(92)90268-F)
25. Iranmanesh, Onur, "Generation gap, learning from the experience of compulsory remote architectural design studio", 5.
26. Hong, El Antably, Kalay, "Architectural Design Creativity in Multi-User Virtual Environment: A Comparative Analysis between Remote Collaboration Media", 829.
27. Ibid., 832.
28. Shantanu Tilak, Michael Glassman and Irina Kuznetcova, "Multi-User Virtual Environments (MUVES) as Alternative Lifeworlds: Transformative Learning in Cyberspace", *Journal of Transformative Education*, 18(4) (2020): 310-337, doi: <https://doi.org/10.1177/1541344620932224>
29. Ibid.
30. Stephan Sonnenburg, "Creativity in Communication: A Theoretical Framework for Collaborative Product Creation", *Creativity and Innovation Management*, 13(4) (2004): 254-262, doi: <https://doi.org/10.1111/j.0963-1690.2004.00314.x>
31. Ibid.
32. Ibid.
33. D. Randy Garrison, *E-learning in the 21st Century: A Framework for Research and Practice*, third edition (London; New York: Routledge, 2017).
34. Ken Yocom, Gundula Proksch, Branden Born, Shannon K. Tyman, "The Built Environments Laboratory: An Interdisciplinary Framework for Studio Education in the Planning and Design Disciplines", *Journal for Education in the Built Environment*, 7(2) (2012): 8-25, doi: <https://doi.org/10.11120/jebe.2012.07020008>
35. Spyros Vosinakis, Panayotis Koutsabasis, "Interaction Design Studio Learning in Virtual Worlds", *Virtual Reality*, 17 (2013), 60.
36. Burak Pak, Caroline Newton, Johan Verbeke, "Virtual worlds and architectural education: A typological framework", in Henri Achten, Jiri Pavlicek, Jaroslav Hulin, Dana Matejovska, eds., *Digital Physicality Proceedings of the 30th eCAADe Conference*, Vol. 1. Paper presented at the 30th eCAADe conference in Prague, 12-14 September 2012 (Czech Republic: Czech Technical University in Prague, 2012), p. 739-746. Retrieved from: <https://cumincad.architexturez.net/doc/oai-cumincadworks-id-ecaade2012-234>
37. Vosinakis, Koutsabasis, "Interaction Design Studio Learning in Virtual Worlds", 66.
38. Ken Yocom, Gundula Proksch, Branden Born, Shannon K. Tyman, "The Built Environments Laboratory: An Interdisciplinary Framework for Studio Education in the Planning and Design Disciplines", *Journal for Education in the Built Environment*, 7(2) (2012), 8-25, doi: <https://doi.org/10.11120/jebe.2012.07020008>
39. Thérèse Tierney, *Abstract Space: Beneath the Media Surface* (London; New York: Taylor & Francis, 2007).
40. Lawrence Bird, Guillaume LaBelle, "Re-Animating Greg Lynn's Embryological House: A Case Study in Digital Design Preservation", *Leonardo*, 43(3) (2010), 245.
41. Mario Carpo, *The Alphabet and the Algorithm* (Cambridge, Mass.: The MIT Press, 2011), 40.
42. Greg Lynn, *Folds, Bodies & Blobs: Collected Essays* (Brussels: La lettre volée, 1998).
43. Lynn, *Animate Form* (New York: Princeton Architectural Press, 1999).
44. Bernard Cache, *Earth Moves: The Furnishing of Territories*, edited by Michael Speaks, trans. Anne Boyman (Cambridge, Mass.: The MIT Press, 1995); Lynn, *Bernard Cache, Objectile: Archaeology of the Digital 09* (Montreal: Canadian Centre for Architecture, 2015).
45. Gilles Deleuze, *Le Pli : Leibniz et le Baroque* (Paris: Les Editions de Minuit, 1988); Deleuze, *The Fold: Leibniz and the Baroque*, trans. Tom Conley (Minneapolis: University of Minnesota Press, 1992).
46. Carpo, *The Second Digital Turn: Design Beyond Intelligence* (Cambridge, Mass.: London: The MIT Press, 2017), 8.
47. Engin Isin, Evelyn Ruppert, *Being Digital Citizens* (London: Rowman & Littlefield International, 2020), 139.
48. Carpo, *The Second Digital Turn: Design Beyond Intelligence*.
49. Charitonidou, "Urban scale digital twins in data-driven society: Challenging digital universalism in urban planning decision-making", *International Journal of Architectural Computing*, 20(2) (2022): 238-253, doi: <https://doi.org/10.1177/14780771211070005>
50. Yanni Alexander Loukissas, *All Data Are Local: Thinking Critically in a Data-Driven Society* (Cambridge, Mass.: The MIT Press, 2019); Anita Say Chan, *Networking Peripheries Technological Futures and the Myth of Digital Universalism* (Cambridge, Mass.: The MIT Press, 2014).
51. Aksel Ersoy, Klaus Chaves Alberto, "Understanding urban infrastructure via big data: The case of Belo Horizonte", *Regional Studies, Regional Science*, 6(1) (2019): 374-379.
52. Loukissas, *All Data Are Local: Thinking Critically in a Data-Driven Society*.