Computers Are Like Telescopes:

Deeper Engagements with thinking, applying and positioning computation in design research

Class Meeting Times
Tuesdays: 9:30pm – 12:30pm // 2:00pm - 5:30pm
Thursdays: 9:30pm – 12:30pm // 2:00pm - 5:30pm

Studio Director: Maya Przybylski
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Office hours (by appointment)

Computer Science is no more about computers than astronomy is about telescopes.

Edsger Dijkstra (1930-2002)
Turing Award winning computer scientist

Computer science is not really about computers – and it's not about computers in the same sense that physics is not really about particle accelerators, and biology is not about microscopes and Petri dishes...and geometry isn't really about using surveying instruments. Now the reason that we think computer science is about computers is pretty much the same reason that the Egyptians thought geometry was about surveying instruments: when some field is just getting started and you don't really understand it very well, it's very easy to confuse the essence of what you're doing with the tools that you use.

Hal Abelson (1986)
Professor of Computer Science and Engineering at the MIT

Computation and creativity should be mutually supportive in the design process. For this to be possible, computation must be understood in a broad sense, encompassing both the narrow, digital kind of computation and the more general kind of computation in which objects may only have digital approximations.

Terry Knight & George Stiny (2001)

Today we're beginning to realize that the new media aren't just mechanical gimmicks for creating worlds of illusion, but new languages with new and unique powers of expression.

Marshall McLuhan (1960)

The ability to 'read' a medium means you can access materials and tools created by others. The ability to 'write' in a medium means you can generate materials and tools for others. You must have both to be literate. In print writing, the tools you generate are rhetorical; they demonstrate and convince. In computer writing, the tools you generate are processes; they simulate and decide.

Alan Kay (1989)
Xerox PARC and Apple

INTRODUCTION

Since the advent of computer-aided design in the 1980s, the toolset afforded by the digitization of the design process has steadily expanded.[1] A notable recent expansion has been in the area of design computation which focuses on an expanded view of the computer and its potentials. Instead of viewing the computer primarily as a digitizer of things previously done manually, such as the use of drafting software to replace drafting by hand, design computation is focused on the designers' engagement with the underlying processes and logic of a computer's rule-based intelligence in order to explore potentials, through the development of custom tools, not afforded by out-of-the-box software.[2]

Dr. Peter J. Denning, an American computer scientist known for his expertise in communicating computing principles, states "the fundamental question underlying all of computing is, What can be (efficiently) automated."[3] In posing this question in such general terms, Denning opens the door for disciplines, outside of the computing sciences, to explore what potentials are uncovered when the automating, or computing, potentials of their familiar digital tools are unleashed: Medical imagery and modeling has taken advantage of such potential in automating diagnostic processes and automated exploration of medical models such as the genome. Geography has embraced the automation of raw geo-referenced data to generate visual representations through Geographic Information Systems (GIS). The field of literature has automated stylistic analysis of texts in order to expose patterns in literary works.[4]

Architecture too, has turned its attention to the opportunities found in automation. Computational Design has emerged as a new territory of applied research within the architectural community whereby designers engage with the underlying principles of the computer's automating capabilities in order to explore formal, material and organizational strategies by way of processing. In the architectural context, there is a wide range of processes that can benefit from automation. At one end, there are automated processes, such as a door schedule generator within a Building Information Modeler, that speed up familiar (and often mundane) tasks; at the other are powerful exploratory processes, such as environmental performance simulators and evolutionary algorithms, that afford new levels of engagement and expose new potentials.

Within a relatively short history, those engaging in computational design in architecture have built an impressive body of work.[5] We can easily identify several themes within the discourse: First, computational integration has led to explorations in algorithmically generated forms and visualizations, known as creative coding.[6,7] This approach in form generation is expanded by combining environmental and structural performance concerns.[8] Another well-established theme of computationally-oriented research is centered on the use of digital fabrication tools in the production of physical objects.[9,10] Responsive Architecture, or digitally-driven architecture, presenting the potentials for a dynamic architecture, changing its environmental qualities as it receives stimuli from its surrounding, is also using computationally-oriented methods and tools.[11] Data-driven practices, focused on things like automated analysis and site-finding are also gaining traction .[12]

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1. Steele, James. *Architecture and Computers: Action and Reaction in the Digital Design Revolution*. New York: Watson Guptill Publications, 2002.
2. Terzidis, Kostas. *Algorithmic Architecture.* 1st ed. ed. Burlington, MA: Architectural Press, 2006.
3. Denning, Peter J. "Computer Science: The Discipline" (1999): p 3. Web. July 14, 2011 (http://cs.gmu.edu/cne/pjd/PUBS/ENC/cs99.pdf). Flake, Gary William. The Computational Beauty of Nature: Complex Explorations of Fractals, Chaos, Complex Systems, and Adaptation. Massachusetts; London England : MIT Press, 1998.
4. Koppel M., Argamon S., Shimoni A. *Automatically Categorizing Written Texts by Author Gender:* Literary and Linguistic Computing 17(4).2004
5. CumInCAD.org offers cumulative index of publications about computer aided architectural design. It includes bibliographic information about over 12,300 records from journals and conferences such as ACADIA, ASCAAD, CAADRIA, eCAADe, SIGraDi, ASCAAD and CAAD futures.
6. Reas, Casey, McWilliams, Chandler. Form+Code in Design, Art, and Architecture (Design Briefs). Princeton Architectural Press. 2010.
7. Aranda, Benjamin. Tooling. Ed. Chris Lasch. 1st ed. ed. New York: Princeton Architectural Press, 2006.
8. Tsigkari, Martha. Davis, Adams. Aish, Francis. A Sense of Purpose: Mathematics and Performance in Environmental Design. Architectural Design Journal: Mathematics of Space. Volume 79, Issue 2, pages 55–57. July 2011.
9. Manufacturing Material Effects: Rethinking Design and Making in Architecture. Ed. Kolarevic, Branko and Klinger, Kevin. New York: Routledge, 2008.
10. Iwamoto, Lisa. Digital Fabrications: Architectural and Material Techniques (Architecture Briefs). Princeton Architectural Press. 2009.
11. Knight Terry, Stiny, George. Classical and Non-Classical Computation in Information Technology. Volume5, Number 4, pages 355 - 372. 2001.
12. De Monchaux, Nicholas. 2016. Local Code - 3,659 Proposals about Data, Design & the Nature of Cities. New York: Princeton Architectural Press.

In addition to the continued development of these technically-driven concerns, a new set of practices, concerned less with the application of computation and more with its positioning, are emerging. As the field enters its third decade, it is pushing to move studio- and lab-scaled experiments out of test-bed environments towards real-world deployments. As projects move from test-spaces with relatively minimal risks, to real-world applications with potentially more serious outcomes, we need to incorporate a broader set of concerns, including social, political and ethical awareness, to acknowledge the projects' increasingly complex context.[13] Further, given the hybrid nature of some computational design practice, where physical artifacts and virtual components work together to mediate the environment, designers need to exercise the same criticality they have shown the physical project components towards the virtual project components operating inside the computer and the relationship between the two.[14] In other words, a more robust notion of computational literacy in needed where in the data we integrate and the algorithms we code are understood and examined as designed project elements with agency over project outcomes – not only from a technical perspective, but also with respect to social and cultural impacts.[15]

It is within this broad impression of computation that this studio will operate. It offers a forum to encourage a varied set of readings and explorations on the nature and practices of computation in design. Specifically, how do the increased availability of data, the emergence of computational design, and accessible computational platforms transform the theoretical frameworks, methodologies, tools and outcomes of the architect? The studio will support the varied nature and modes of engagements with computation in design. It aims to nurture critical relationships between students' work and the tools and processes they engage. It values an open-ended relationship with computation, which does not presuppose a specific use or outcome, but instead presents avenues for design-based inquiry. Three modes of engagements with computation are proposed to help situate and stimulate thesis development:

Thinking Computation: Developing design-oriented algorithmic thinking is key to rich engagement with design computation. 'Thinking computation' does not imply a specific technology, outcome or concern; instead it demands close attention to the organization of information and the use of rule-based logical processes, which are the foundation of a computationally-oriented design practice. Computational thinking, as a concept divorced from any specific technical implementations, has great value beyond explicitly computationally-oriented projects. Specifically, computation can support projects concerned with complex spatial systems, and provides a language and framework for handling the complex and interconnected dynamics of these conditions.

Applying Computation: The computational designer is able to abstract a problem for initial action and then, employ computational techniques to incrementally rebuild the lost complexity, thereby allowing the original richness of the problem space to be maintained. This requires the development of a new set of technical skills that enable designers to engage a computer's processing capabilities in a more open-ended manner. Thus, the ability to read and write instructions (i.e. to code) is a necessary skill for designers. Applying Computation involves building your own computational tools or processes using selected languages and platforms.

Positioning Computation: As we enter new frontiers in computational design, it is no longer enough to only have methods that integrate computation and data in design projects but new methods are needed that engage with it critically throughout the design process and beyond. Sensing, thinking, representing and making computationally has shaped design practice and outcomes in the past decade. As a result, there are numerous opportunities to extend considerations around computation in design beyond technical and material issues to engage with the social, cultural, political and theoretical aspects of computationally-informed design practice.

OBJECTIVES

The primary goal of the studio is to support the development of an architecture thesis. Students will be challenged to articulate a thesis question that goes beyond a discrete problem solving exercise to critically engage with the discipline of architecture. Emphasizing design-oriented practice, through blending thinking and doing activities, students will position their work within contemporary discourse and consider how to connect their work to the world.

13. Shepard, Mark. 2011. "Toward the Sentient City." In Sentient City: Ubiquitous Computing, Architecture and the Future of Urban Space, edited by Mark Shepard, 16-37. Cambridge : The MIT Press
14. De Monchaux, Nicholas. 2016
15. Kitchin, Rob and Dodge,Martin. 2011. Code/Space: Software and Everyday Life. MIT Press.

Recognizing that this term marks a student's first formal phase of thesis work, the studio prioritizes the concurrent development of a clearly articulated set of concerns, supporting methods, and required resources that will work together to firmly set out a trajectory for their Masters theses. The studio is geared towards design-oriented theses where broadly interpreted design activities are intended to complement more traditional modes of scholarship.

By the end of the course students will:

> articulate a stimulating thesis question which engages architectural discourse from a design-oriented perspective

> situate their work amongst a collection of identified allies and/or opponents – these can include project precedents, site contexts, methods, tools, critical/theoretical texts,…, found both within and outside the discipline of architecture

> propose design-oriented methods to be used to address their thesis question

> test their proposed methods through a preliminary set of self-directed design exercises or experiments

> iteratively move through various modes of research – including designing, making, reading, recording, analyzing, and writing – to support the development of their thesis

STRUCTURE

The studio structure supports iterative development of an architecture thesis. Students will engage in a variety of activities intended to build traction and momentum in confronting the challenges of thesis. Several different formats are planned for studio sessions over the course of the term: Project 1: Allies and Opponents, in which students situate their work, is supported by shared discussions on and responses to assigned readings via seminars. Project 2: Toolkits - Methods & Resources, where students explore the specifics of *how* they might address the concerns raised in their thesis topic, is supported primarily through individual and small-group meetings. The third project, Illustrated Syllabus, in which students produce a written text outlining their thesis proposal, is organized around intensive reading/response sessions carried out in small groups of 3-4 students. During this phase, each student will also lead a seminar session in which they present a key text used in their thesis alongside their project and then lead a studio-wide discussion. The last phase of the studio, entitled Thesis v1.0, sees students running through a first robust iteration of their design as informed by the work done to date. During this time, mostly individual meetings will be planned to support the specifics of each project acutely. Additionally, two workshop sessions are planned. The topic(s) for these will be decided in response to the group's needs/interests.

Offered below are brief descriptions of each phase of work. Detailed project descriptions and expectations will be presented at the start of each phase. While the projects are developed with design-oriented research activities in mind, descriptions will be open-ended enough to support other modes of research.

PROJECT 1: ALLIES AND OPPONENTS (INTRO: SEPTEMBER 6 / DUE: SEPTEMBER 20, 5 SESSIONS)

In this phase, you will identify resources that resonate with your thesis interests. These will become your allies as you move forward in your work and can include written texts, sites, scenarios, representation techniques, precedent projects, or specific tools or technologies. This survey will be used to better understand and share your interests, sharpen your thesis question, and guide subsequent progress. You will leave this phase of work with a revised thesis question and a preliminary sense of how it connects with existing discourse and practice.

PROJECT 2: TOOLKITS - METHODS & RESOURCES (INTRO: SEPTEMBER 20 / DUE: OCTOBER 16, 6 SESSIONS)

Rather than presupposing the manner in which you will address your thesis question through design activity, you will explore various methods, or combinations thereof, that can be deployed to address the specific challenges identified in your work. During this phase, you will select and analyze precedent projects from the perspective of methodology to better understand potential models for ways of working. Using your analysis of these case-studies as a point of departure you will carry out mini-experiments testing the potentials of methods for your own project.

Along the way, you will need to populate your project space with additional resources – this can include site information, GIS-data, policy documents, material samples and stock, technological platforms, additional literature, etc. During this phase, you will also begin assembling these resources not only to better represent and engage your project but also to better understand the challenges you may face in their acquisition and the resulting constraints you may need to consider.

This phase is characterized by quick methodology-oriented experiments or charrettes which foreground the idea that design activities and research activities can happen in parallel rather than in series. In this course, it is thought that an intense dialogue between traditional modes of scholarship and design work nurtures a rich context for thesis development. You will leave this phase of work with a better sense of how you plan to work and what resources, skills and knowledge you need to acquire to make this possible. These inputs into your project space will yet again inform a sharpening of your thesis question.

PROJECT 3: ILLUSTRATED SYLLABUS (INTRO: OCTOBER 16 / DUE: NOVEMBER 18, 8 SESSIONS)

With a better sense of what your thesis question is, how it engages architectural discourse, and the manner in which you will carry out design activities, you are ready to begin to more formally articulate your thesis proposal. During this phase, you will clarify your theoretical positioning, expand on site documentation and motivate your design approach through the development of an illustrated syllabus. Pithy text and considered representations will work together to present your thesis argument wholistically for the first time. The produced document will include preliminary attempts at many of the components expected to constitute your final document including: an abstract, a thesis question including objectives, its context communicated via literature and precedent review, the planning, motivation and position on design approach or methodology, preliminary diagrams, site research, project timeline and bibliography.

PROJECT 4: THESIS V1.0 (INTRO: NOVEMBER 18 – DUE: DECEMBER 12, 5 SESSIONS + STUDY WEEK)

You will utilize the argument you prepared in the previous phase and test its potential in driving design-oriented activities in service of your thesis. In this phase of the course you will develop the first robust iteration of your thesis design work. The hope is that this work establishes the design foundations of your thesis project which will be refined over the terms to come.

PROJECT 5: FINAL FOLIO SUBMISSION (DUE DECEMBER 18)

After the final reviews, you will assemble your term's work (4 projects) into a comprehensive portfolio archiving your thesis development.

SUPPORTING SEMINARS

We will use the seminar format to share responses to instructor-selected and student-led readings during the first half of the term. The purpose of the instructor-led readings is to situate and expose the group to some of the key issues in and around computationally-oriented practice in architecture. After 3 such sessions, the format will switch to student-led seminars where each student will be required to run their own seminar (or part thereof) – which includes selecting a reading, relevant to their own project, and moderating a discussion of the text in the context of their own project's development. The student-led seminars are seen as an opportunity for a focused discussion on the positioning and development of a specific thesis project.

In general, our approach to reading will be highlighted by responses to two things: 1) we will evaluate and respond to readings with respect to the specific content they offer and 2) we will also play close attention to their structure and coherence as a research document. In dealing with the second concern, students will become more familiar with approaches to structuring and exploring their questions in written form. Instructor-selected readings and a broader list of recommended readings are included at the end of this document (page X).

GRADING BREAKDOWN

Project 1: Allies & Opponents	10%
Project 2: Toolkits & Resources	15%
Project 3: Illustrated Syllabus	25%
Project 4: Thesis v1.0	25%
Project 5: Final Folio Submission	10%
Participation (seminars, reviews, meetings):	15%

SCHEDULE

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	
WEEK 1	2 SEPTEMBER	3	4	**5** AM TRD Studio Intros	**6** AM Course & Project 1 Intros Location: Rm. 2026 PM Work Session	7	8
WEEK 2	9	10	**11** AM Seminar Location: Ward Room PM Individual Meetings Location: Studio	12	**13** AM/PM Mini-pinups of Project 1 progress Group Format Location: Loft Gallery	14	15
WEEK 3	16	17	**18** AM/PM Individual Meetings Location: Studio	19	**20** **PART 1 DUE** **AM /PM** **PROJECT 1** **PRESENTATIONS** **LOCATION:** **Loft Gallery** Part 2 Intro	21	22
WEEK 4	23	24	**25** AM Seminar Location: Photo Studio PM Individual Meetings Location: Studio	26	**27** AM/PM Individual Meetings Location: Studio	28	29
WEEK 5	30	1 OCTOBER	**2** AM Seminar Location: Photo Studio PM - Loft Gallery Group Format Meetings Joint Crit Session with Jane's group - TBC	3	**4** AM/PM - Loft Gallery Group Format Meetings Joint Crit Session with Jane's group - TBC	5	6
WEEK 6	7	8 **THANKSGIVING DAY** **NO CLASSES**	9 **Study Day** No Classes Scheduled	10 **Study Day** No Classes Scheduled	**11** **Study Day Makeup** Tuesday Schedule AM Part 3 Intro - Ward Room AM/PM Individual Meetings Location: Studio	12	13
WEEK 7	14	15	**16** **PART 2 DUE /** **MID-REVIEW** **AM /PM** **PROJECT 2 REVIEW** **LOCATION:** **LOFT GALLERY**	17	**18** NO CLASS MAYA @ ACADIA	19	20

continued...

SCHEDULE CONTINUED...

	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	
WEEK 8	21	22	**23** AM - Photo studio Student-Led Seminars (4 projects) PM - Ward Room Group-Reading Meetings	24	**25** AM - 2026 Student-Led Seminars (4 projects) PM - 2026 Group-Reading Meetings Location: TBD	26	27
WEEK 9	28	29	**30** AM - Photo Studio Student-Led Seminar (3 Projects) PM - 2026 WORKSHOP DAY 1	31 NOVEMBER	**1** AM/PM WORKSHOP DAY 2 Location: E-Classroom	2	3
WEEK 10	4	5	**6** AM - Photo Studio Student-Led Seminars (4 projects) PM - 2026 Group-Reading Meetings Location: TBD	7	**8** AM/PM - 2026 Group-Reading Meetings Location: TBD	9	10
WEEK 11	11	12	**13** **PART 3 DUE** **AM /PM** **PART 3 PRESENTA-TION** **LOCATION:** **LOFT GALLERY** Part 4 Intro	14	**15** NO CLASS MAYA @ AHRA	16	17
WEEK 12	18	19	**20** AM/PM Individual Meetings Location: Studio	21	**22** AM/PM Individual Meetings Location: Studio	23	24
WEEK 13	25	26	**27** AM/PM Individual Meetings Location: Studio	28	**29** AM/PM Individual Meetings Location: Studio LAST DAY	30	1 DECEMBER
	2	3	4 AM/PM Dedicated Office Hours for Maya's TRD1 group Optional meetings	5	6 AM/PM Dedicated Office Hours for Maya's TRD1 group Optional meetings	7	8
	9	10	11	**12** AM/PM TRD1 FINAL REVIEWS DAY 1 - TBC	**13** AM/PM TRD1 FINAL REVIEWS DAY 2 - TBC	14	15

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OFFICIAL BUSINESS

ATTEND MEETINGS AND SEMINARS. WORK IN STUDIO.

Work in studio on studio days. Be in full attendance in studio from 9:30-12:30pm and 2:00- 5:30pm on studio days. If you are planning to visit the library or conduct off site research, please talk to your instructor.

DEADLINES / ACCOMMODATION FOR ILLNESS; NOT FOR TRAVEL

All assigned parts of the work must be completed. Punctual completion is required. Late submissions without approved extensions will lose 10% of project value per day.

If you need to apply for accommodation of lateness or absence due for illness, make a formal application by using 'Verification of Illness' [VIF] forms or counseling letters, filed with the Architecture Office. Student travel plans are not considered grounds for granting alternative reviews and submission times.

DIGITAL SUBMISSIONS

Digital files are required to accompany all major project submissions. These submissions will be carried out using LEARN.

REVIEWS

Please note that reviews are instructive and not evaluative. It is therefore important for each individual to participate in both the review of their own work, and in the reviews of the work of fellow students. Participation in reviews is mandatory.

COMMUNICATION

LEARN will be used as a communication and dissemination tool.You will receive general communications from the coordinator regarding studio business. It is expected that you check your email address regularly.

ACADEMIC INTEGRITY, GRIEVANCE, DISCIPLINE, APPEALS, AND STUDENTS WITH DISABILITIES

Academic integrity: In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. [Check the Office of Academic Integrity for more information.]

Grievance: A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70, Student Petitions and Grievances, Section 4. When in doubt, please be certain to contact the department's administrative assistant who will provide further assistance.

Discipline: A student is expected to know what constitutes academic integrity to avoid committing an academic offence, and to take responsibility for his/her actions. [Check the Office of Academic Integrity for more information.] A student who is unsure whether an action constitutes an offence, or who needs help in learning how to avoid offences (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course instructor, academic advisor, or the undergraduate associate dean. For information on categories of offences and types of penalties, students should refer to Policy 71, Student Discipline. For typical penalties, check Guidelines for the Assessment of Penalties.

Appeals: A decision made or penalty imposed under Policy 70, Student Petitions and Grievances (other than a petition) or Policy 71, Student Discipline may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to Policy 72, Student Appeals.

Note for students with disabilities: AccessAbility Services, located in Needles Hall, Room 1132, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with AccessAbility Services at the beginning of each academic term.

REQUIRED SEMINAR READINGS & SCEHDULE

Materials will be made available electronically through LEARN or University of Waterloo's library system.

TUESDAY SEPTEMBER 11 – THINKING

Sean Ahlquist and Achim Menges, "Computational Design Thinking", in Computational Design Thinking, AD Reader. Wiley, 2011, p. 10-29.

Mario Carpo, "The Second Digital Turn" in The Second Digital Turn: Design Beyond Intelligence, Cambridge: MIT Press, 2017, p.9-97.

Neil Leach, "There is No Such Thing as Digital Design" in Paradigms in Computing: Making, Machines, and Models for Digital Agency in Architecture (eds David Jason Gerber, Mariana Ibanez), Los Angeles: eVolo Press, 2014, p. 148-158.

TUESDAY SEPTEMBER 25 - APPLYING

Armstrong R. "Informed Speculation: An ill-tempered foundation for Venice" in Columbia University Graduate School of Architecture, Planning and Preservation, 2015. Available at: http://www.arpajournal.net/informed-speculation/.

De Moncheaux, Nicholas. Local Code: 3659 Proposals About Data, Design, and the Nature of Cities. Princeton Architectural Press, 2016. (14-60, 154-177).

Menges, A.: 2008, Integral Formation and Materialisation: Computational Form and Material Gestalt, in B. Kolarevic and K. Klinger (ed.), Manufacturing Material Effects: Rethinking Design and Making in Architecture, Routledge, New York, pp. 195–210.

TUESDAY OCTOBER 2 - POSITIONING

Barns, Sarah. "Visions of Urban Informatics: From Proximate Futures to Data-Driven Urbanism" in The Fibreculture Journal, Issue 29: Computing the City. Available at: http://twentynine.fibreculturejournal.org/fcj-214-visions-of-urban-informatics-from-proximate-futures-to-data-driven-urbanism/

Mario Carpo, "Digital Darwinism: Mass Collaboration, Form-Finding, and The Dissolution of Authorship" in Log, No. 26 (Fall 2012), pp. 97-105 (Stable URL: http://www.jstor.org/stable/41765764)

Pablo Lorenzo-Eiroa, "From Coding to Representation, To Formal Autonomy, To Media Reproduction: Four Levels of Architecture Agency" in Paradigms in Computing: Making, Machines, and Models for Digital Agency in Architecture (eds David Jason Gerber, Mariana Ibanez), Los Angeles: eVolo Press, 2014, p. 206-221.

RECOMMENDED READINGS & EXPANDED BIBLIOGRAPHY

Rachel Armstrong, "Natural Computing: Operationalizing the Creativity of the Natural World" in Paradigms in Computing: Making, Machines, and Models for Digital Agency in Architecture (eds David Jason Gerber, Mariana Ibanez), Los Angeles: eVolo Press, 2014, p. 190-205.

Beorkrem, Christopher. *Material strategies in digital fabrication*. Routledge, 2013.

Burry, Jane. Burry, Mark. *The New Mathematics of Architecture*. Thames & Hudson. 2010

DeLanda, Manuel. "Material complexity." In Digital Tectonics, Wiley, 2004, p.14-21.

Iwamoto, Lisa. *Digital Fabrications: Architectural and Material Techniques (Architecture Briefs)*. Princeton Architectural Press. 2009.

Aranda, Benjamin. *Tooling*. Ed. Chris Lasch. 1st ed. ed. New York: Princeton Architectural Press, 2006.

Manufacturing Material Effects: Rethinking Design and Making in Architecture. Ed. Branko Kolarevic and Kevin Klinger. New York: Routledge, 2008.

Shannon Mattern, "Methodolatry and the Art of Measure," Places Journal, November 2013. Accessed 31 Jul 2018. https://doi.org/10.22269/131105

Shannon Mattern, "A City Is Not a Computer," Places Journal, February 2017. Accessed 31 Jul 2018.https://doi.org/10.22269/170207

Menges,Achim. Ahlquist, Sean. *Computational Design Thinking*, AD Reader. Wiley, 2011

Menges, Achim, Tobias Schwinn, and Oliver David Krieg, eds. *Advancing Wood Architecture: A Computational Approach*. Routledge, 2016.

Menges, A.: 2008, Integral Formation and Materialisation: Computational Form and Material Gestalt, in B. Kolarevic and K. Klinger (ed.), Manufacturing Material Effects: Rethinking Design and Making in Architecture, Routledge, New York, pp. 195–210.

Architectural Geometry. Ed. Helmut Pottmann and Daril Bentley. 1st ed. ed. Exton, Pa.: Bentley Institute Press, 2007.

Reas,Casey. McWilliams, Chandler. *Form+Code in Design, Art, and Architecture (Design Briefs)*. Princeton Architectural Press. 2010.

From Control to Design : Parametric/Algorithmic Architecture. Ed. Tomoko Sakamoto and Albert Ferré. New York: Actar-D, 2007.

Schindler, C.: 2008, Information-Tool-Technology (Translation of: Die Mittel der Zeit - Herstellungsinnovation im Holzbau), in Hensel, M., Menges, Form Follows Performance: ZurWechselwirkung von Material, Struktur, Umwelt, ArchPlus No. 188, ArchPlus Verlag, Aachen. (ISSN05873452)

Terzidis, Kostas. *Algorithmic Architecture*. 1st ed. ed. Burlington, MA: Architectural Press, 2006.

Tufte, Edward R., 1942-. *Envisioning Information*. Cheshire, Conn.: Graphics Press, 1990.

Tufte, Edward R. *The Visual Display of Quantitative Information*. Cheshire, Conn.: Graphics Press, 1983.

ARCHITECTURAL DESIGN JOURNAL – SEVERAL ISSUES INCLUDING:

Material Synthesis: Fusing the Physical and the Computational. Volume 85, Issue 5, July/August 2015

Computation Works: The Building of Algorithmic Thought, Volume 83, Issue 2, July/August 2013

Material Computation: Higher Integration in Morphogenetic Design, Volume 82, Issue 2, July/August 2012

The New Structuralism: Design, Engineering and Architectural Technologies, Volume 80, Issue 4, July/August 2010