BUILDERS OF THE VISION

Technology and the imagination of design

By

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Abstract

This dissertation identifies and documents a "technological imagination of design" emerging around the reconfigured discourses of design and design representation by the culture of technology production in the *Computer-Aided Design Project,* a Cold War era research operation funded by the US Air Force at MIT, tracing it into its contemporary deployment in the technology project known as *Building Information Modeling*.

Exploring the discursive and technological linkages between these two sites, the dissertation outlines the ongoing project of construing technological centrality and universality as the dominant trope in discourses about design production. An expanded critical perspective on design is thus developed that looks at technological systems —such as software— and the cultures that produce them, with their histories and regimes of power, as crucial participants in, rather than as neutral vessels for, the design and production of our built environment.

The dissertation ranges from examining the politics of representation, participation and authorship in the systems imagined by members of the *Computer-Aided Design Project* —in particular that of Steven Coons and Nicholas Negroponte's "man-machine" design systems— to discussing the culture of BIM coordination through an ethnographic portrait and data-visualization of its practice at *Gehry Technologies,* in two large-scale projects in the United Arab Emirates.

As this study demonstrates, technological discourses and artifacts act as brokers for culturally dominant conceptions of design, representation, and work.

Thesis Supervisor: Terry W. Knight
Title: Professor of Design and Computation

BIOGRAPHY

Daniel Cardoso Llach grew up in Bogotá, Colombia. He earned a Bachelor of Architecture from Universidad de los Andes, and subsequently taught there from 2002 to 2005. He then earned a Masters of Science in Architecture Studies (SMArchS) at MIT. His thesis explored the generative potential, and cultural dimension, of digital fabrication for architecture. It was funded by the Center of Bits and Atoms at the MIT MediaLab, and was awarded the Best SMArchS Thesis prize. In 2007, he started his doctoral program with the support of a Presidential Fellowship. He has lectured and conducted numerous workshops on computational design in universities in Latin America, the US, and the Middle East, and published several articles on peer-reviewed publications. Cardoso Llach recently co-chaired the editorial board of the *Sigradi* (Iberoamerican Society of Digital Graphics) international conference, and is a member of the scientific committee of several academic bodies including *Sigradi*, the *International Committee for Design History and Design Studies*, and the *Dearq* journal. As an architect and computational specialist, Cardoso Llach has consulted for *Gehry Technologies* (Middle East) and *Kohn Pedersen Fox* (New York), as well as an independent licensed architect and designer in his native Bogotá.

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First of all, I'd like to thank my colleagues and interlocutors at MIT and Gehry Technologies, Abu Dhabi, for their openness and friendship during my time as a researcher and colleague. My hope is that this study helps raise novel questions and insights about the practices they all know so well.

Terry Knight, my committee chair, offered me unwavering support and friendship during the many stages of my doctoral work at MIT. Her attentive reading and criticism of this dissertation's drafts taught me about intellectual generosity and academic rigor. I am also grateful to her for letting me collaborate repeatedly in the Inquiry into Design and Computation course. This dissertation expands on the themes and questions nurtured there.

I am grateful to Lucy Suchman, who encouraged me in my quest to take on the difficult questions about humans and machines concerning design, and motivated me to explore new forms of academic inquiry. From her I learned the strength of critical, constructive, engaged, scholarship. I am also indebted to her for the detailed reading and commenting of the drafts, and for hours of truly generative conversations.

Rosalind Williams, who joined the committee at a later stage, showed me new ways to think about technology's ties with the imagination and desire. I am indebted to her for teaching me to be wary of the cloudbanks of theorizing, and for long email conversations that generated crucial insights for this project.

I am thankful to Takehiko Nagakura, who always offered me concise and sharp criticism, forcing me to always look at my work from different perspectives.

Besides my committee, other scholars have been key to the development of the arguments in this study, and to my own intellectual growth. I would specially like to thank Leo Marx for encouraging me to nurture my critical voice, and George Stiny, for showing me ways to think about design as an irreducibly open-ended practice. I would also like to thank Dennis Shelden for his generosity in discussing the questions this dissertation explored, and for his willingness to help me find ways to pursue them. This dissertation would have taken a very different shape without his curiosity and interest. I also thank Nasser Rabat and Bill Porter, for contributing in various ways to this dissertation. The late Bill Mitchell's intellectual rigor, generosity and personal warmth will always be a reference for me. I feel very lucky for having had the chance of being his student and collaborator during a good part of my life at MIT.

The community at the MIT archives and the MIT Museum collections provided me with access to crucial materials for my research. In particular, I'm indebted to Denise Wernikoff and Theresa Smith for going out of their way to provide me with prompt access to documents and artifacts from the early days of computation at MIT.

I'm also very grateful to MIT Anthropology and STS faculty and students. Hanna Rose Shell's writing seminar was a crucial arena of conversation and constructive critical feedback. I am thankful to the participants, among them David Singerman, Teasel Muir-Harmony and Rebbecca Uchill, whose feedback on some very early drafts helped me shape the questions from which this dissertation later emerged.

I have published earlier versions of some of this dissertation's chapters, which have benefited from the process of editorial review. These include Thresholds, edited by Adam Johnson; Dearq journal, edited by Maarten Goosens, and AD Architectural Design, edited by Xavier De Kestelier and Brady Peters. I thank them, and the journal's reviewers, for providing me with valuable criticisms that challenged me to sharpen some of the arguments in the text. I also would like to thank the Society for the Social Studies of Science (4S) conference in Tokyo, 2010, for a great atmosphere of discussion and debate where I had the privilege of presenting early portions of this dissertation. I would also like to thank Axel Paredes for the opportunity to share early stages of this work with the architecture community at the Universidad Francisco Marroquín (UFM) in Guatemala City.

An early source of insight, questions and inspiration for this research was a series of workshops on computational design and fabrication I taught and co-taught mainly during the early years of my doctorate in Universidad de Chile, Santiago; Universidad Peruana de Ciencias Aplicadas, Lima; Harvard University, Cambridge; Lynden High School, Lynden; Cornell University, Ithaca; Universidad de los Andes, Bogotá; Universidad Francisco Marroquin, Guatemala, and American University of Sharjah. I would like to thank the students, fellow instructors and enablers of these workshops, among them John Snavely, Skylar Tibbits, Kenfield Griffith, Axel Paredes, Rafael Villazón, Pablo C. Herrera, Bob McNeel, Taro Narahara, Santino Medina and Maher El Khaldi.

The MIT Department of Architecture was my home, and also a crucial source of support for this dissertation. I want to thank specially Renee A. Caso for her friendship and advice on all matters including the robust —yet sometimes intricate— administrative scaffoldings of doctoral life at MIT; Annette Horne-Williams, for her assistance on all departmental matters; Daniela Stoudenkova, for her administrative assistance on Design and Computation matters; Duncan Kincaid, Jesse Kaminsky, Eduardo González, Tom Fitzgerald and Ricky Leisersson —from the quasi-legendary "cron" office of the MIT School of Architecture and Planning— for reliably providing crucial assistance on technical matters. I would also like to thank Aurora Brule, from the MIT International Students Office, for helping me navigate countless times the difficult waters of migratory and work regulations.

My work has also benefited from the proximity of my friends and colleagues in the Design and Computation group, whose wonderfully diverse work has greatly inspired and challenged me throughout my life at MIT. I'm grateful to Yanni Loukissas, who has been a crucial interlocutor and source of insight

during the development of this dissertation, and Kenfield Griffith, an unparalleled office mate and teaching partner. I am also grateful to Saeed Arida, Rizal Muslimin, Dina El-Zafaly, Asli Arpak, Onur Gun, Kaustuv Des Biswas, Alise Upitis, Lira Nikolovska, and many more in the group.

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Other friendships were also significant in helping me proceed with my research, sometimes by providing a refreshing space of conversation and thinking outside the boundaries of my work, other times by providing invaluable emotional and practical support. I would like to thank them for the music made and shared, the countless jokes about our scholarly lives, and all the movies and all the conversations. Andres Lombana, Ateya Khorakiwala, Gishnu Das, Yanni Loukissas, Kenfield Griffith, Saeed Arida, Arturo Domínguez, Carlos Rocha and Hyun Lee. I know our conversations will continue.

I would also like to thank my mom, dad, brother and sister, for having always been there despite the prolonged radio silences. Also, I would like to thank my family in-law, for their constant support and love in the distance.

I dedicate this dissertation to Nida, with all of my love, gratitude, and thirst for more adventures together.

CONTENTS

1. INTRODUCTION

Argument outline

This dissertation aims to enrich our understanding of technology's central role in the contemporary production of our built environment. It presents an empirical study of the technology project known in industry as *Building Information Modeling* situated in the context of the intellectual history of computational representations of architecture. It shows how technological discourses and artifacts act as brokers of culturally dominant conceptions of design, design representation, and work.

The dissertation develops predominately around two related lines of inquiry. The first explores the discourses of design articulated by members of the engineering culture developing around the *Computer-Aided Design Project*, a research operation funded by the US Air Force, active between 1959 and 1967, at MIT. I show how the engineers and technologists of the *Project* re-imagined design, in the language of the computer, as the iterative performance of a cybernetic "man-machine" problem-solving engine. I further identify the emergence, in this context, of a new representational tradition expressed by the indexical combination, in the computer, of Albertian perspectivalism and data processing. I submit the thesis that through both technical and discursive innovations, the engineers at the *Project* reconfigured notions of design, design representation, and work, shaping the discourses underpinning the contemporary production of the built environment.[1] To illustrate this, I trace these engineers' technological imagination of design across disciplines, into architecture. On one hand, I situate the work by architectural and design theorist Nicholas Negroponte within the "knowledge space"[2] of the *Computer-Aided Design Project*, highlighting his use of the *Project's* rhetorical and technical instruments to contest traditional conceptions of architectural authorship and practice —moreover, I identify the contradictions of Negroponte's populist claims about technologically enabled bottom-up participation, situating them within a rationalist tradition that ramifies variously into contemporary design cultures. On the other hand, I also review the

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[1] I use "production of the built environment" and "production of architecture" interchangeably throughout the text, as a phrase to avoid the design and construction dualism.

[2] In his study of Gothic cathedral construction, Turnbull uses the expression "knowledge space" to refer to the social and material dimensions of particular contexts of work and practice. David Turnbull, *Masons, Tricksters and Cartographers: Comparative Studies in the Sociology of Scientific and Indigenous Knowledge*, 1st ed. (Taylor & Francis, 2000).

voices of other technology advocates and practitioners who sought, instead, to take advantage of the structured nature of computational representations to increase managerial control in building design and construction. It is in this context of ideas that I situate the technology project of *Building Information Modeling*: not as a rupture with, but as a renewed expression of, aspirations about technology's centrality and universality in design first articulated by members of the *Computer Aided Design Project.*

How these tropes of centrality and universality are constructed —and contested— in practice is this dissertation's second line of inquiry. To explore it, I traveled to the United Arab Emirates as a researcher and consultant at *Gehry Technologies*, where I engaged in the qualitative research tradition of participant observation to draw an ethnographic portrait of *Building Information Modeling*. In my analysis, I place interpretive emphasis on the ways in which architects, engineers and subcontractors manage the conflicts between the abstract conceptualizations of the process —the tropes construing the *Building Information Model* as a neutral, central and universal system— and the everyday challenges of design and construction coordination. I develop, as an interpretive trope, the notion that reconfigurations of design and building practice mobilized by software and *Building Information Modeling*, can be thought of as infrastructural.[3] I conclude my dissertation by presenting a software prototype for the visualization and analysis of the information flows around BIM, arguing that the infrastructural role of software to the production of the built environment demands expanded forms of analysis and criticality.

Prior work: arriving at BIM

Working as a research assistant in digital design and fabrication as a Masters student at MIT, I became interested in a widely circulating metaphor depicting computation's role in design as a *scaffold* for design and creative work.[4] I was fascinated by the way in which that metaphor shaped stories about *both* design and technology, defining *design* as the fluid manipulation of shapes, and computation as a the instrument for the *materialization* of those fluid shapes.[5] I observed that that trope underpinned a good part of the design and fabrication discourse at the Department.[6] For my Masters thesis I developed physical

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[3] As opposed to "instrumental."

[4] I discuss this metaphor in Daniel Cardoso Llach, "A Generative Grammar for 2D Manufacturing of 3D Objects" (Massachusetts Institute of Technology, 2007).

[5] I discuss this in additional detail in Daniel Cardoso Llach, "Design and the Automated Utopia: Certain Assumptions in Digital Design Culture," in *What Matters? Proceedings of the First International Conference on Critical Digital* (presented at the Critical Digital, Harvard University, 2008).

[6] A prominent exception to this view is the work of George Stiny and Terry W. Knight on *Shape Grammars*, an algebraically defined paradigm of visual and material computation. Shape Grammar theory is fundamentally concerned with overcoming the discreteness of computational representations. Stiny —who first formulated the theory— and Knight re-emphasize the irreducibly visual and material dimensions of design through the definition of visual and physical formal languages. Somehow counter-intuitively, Shape Grammar theory seeks to formalize the

prototypes exploring the generative potential of an open-ended "language" of digitally fabricated assembly components.[7] With these artifacts, I speculated about relocating design outside of what I felt was the narrow box of the symbolic, the immaterial, and the "mental," seeking to force it out of a discourse that seemed to reinforce positivist assumptions about mind-body splits, construing design as a process of externalization, or translation[8] of mental images. It was difficult for me to articulate at the time —and still is— but I was convinced that this cognitivist conceptualization of design had a social and political dimension. This dissertation is an attempt to delineate it.

Professor Terry W. Knight —who later became the advisor to this dissertation— pointed me to a 1966 talk by MIT Professor Steven A. Coons, where he described computers —the first computers— as "perfect slaves"[9] enabling artists and architects to be more "creative" by taking care of the "drudgery of physical work." Coons's sharp message opened for me a crucial line of inquiry I started at the Masters level and carried through into my doctoral work.

As a researcher at MIT, while I was busy trying to follow a —now I think romantic— impulse of collapsing design and construction information in order to escape the symbolic "box" where I felt design was being placed, a much larger technological and cultural process was under way, premised on a similar sensibility. *Building Information Modeling* crept into public discourse[10] as the desirable mode of project design and development, supported by promises about efficiency in construction and —more important for my analysis— about its capacity to re-empower the architect as a master builder, thus healing the mythical *Albertian split* between design and construction.[11] As an expression of these cultural shifts, new and sophisticated forms of practice developed around the production, sharing and manipulation of digital

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impossibility of reducing design elements to atomic units. An ambition of this study is to overcome the discreetness of our *discursive* accounts of design, by illuminating the irreducibly social and increasingly technological dimensions of its practice. For an introduction to *Shape Grammar* theory, see

[7] See Cardoso Llach, "A Generative Grammar for 2D Manufacturing of 3D Objects."

[8] I *split* my time between the MIT "Fab Labs" —rooms filled with numerically controlled machinery such as laser cutters and computerized routers— and the papers written by computer pioneers,

[9] See Steven Anson Coons, "Computer, Art & Architecture," *Art Education* 19, no. 5 (May 1, 1966): 9–11.

[10] A 2009 article in the business section of the New York Times describes *Building Information Modeling* as a way to "keep buildings on time and on budget." The technology in question —the modeling software *Digital Project*— is said to "work by modeling, in three dimensions, every odd shape an architect envisions and then letting engineers and architects reconcile the shape with a building's site, ductwork and other features." Described as having an agency of its own, the software is thought to reconcile the "odd" shapes of the architect, Gehry, and the functional demands of construction. The author of the article, by making claims about the reconciliation of form and function, commits to the popular view, which architects like Gehry profoundly dislike, that these two domains were at odds in the first place. Alec Appelbaum, "Frank Gehry's Software Keeps Buildings on Budget," *The New York Times*, February 11, 2009, sec. Business, http://www.nytimes.com/2009/02/11/business/11gehry.html.

[11] Renaissance scholar and architect Gian Battista Alberti contended that architects should be concerned with drawing (*lineamenta*) and leave the construction (*structura*) to a skilled craftsman. This constitutes the Albertian split I refer to in the text. The figure of speech "healing," was used by BIM advocate Chuck Eastman in a guest lecture at MIT in 2008. Charles M. Eastman, "Was Alberti Wrong? The Separation Between Architectural Design and Construction" (presented at the Computation Group Lecture Series, Department of Architecture, MIT, April 28, 2008).

descriptions of buildings, occupying an increasingly large space in discourses about architecture and design.[12] If I can ascribe any anthropological ambition to this study is that of asking what this reconfiguration entails, which voices and perspectives are displaced —and how the voices and experiences of today's design practitioners and thinkers are being shaped by it.

What is Building Information Modeling?

> For over 20 years construction IT researchers have studied aspects related to the representation and interoperability of product model data for construction, an area of technology that is now commonly defined as BIM.[13]

The academic Chuck Eastman, one of the *Building Information Modeling's* most articulate and persistent advocates, defines BIM[14] as "the software tool and process for generating and managing building data during its complete lifecycle, from conceptual design through fabrication, construction, maintenance, and operation of the building."[15] BIM's advocates ambition is to depart from the use of computers as "drafting" aids —a dominant trend of software system since the 1980's— and advance instead data-based *semantic*[16] representations of building elements.

Despite the clear vision, the voices that speak of *Building Information Modeling* are not all the same. The project is pursued by a diverse group of actors including software vendors, academics, authors, industry consortia, government offices, engineers and architects with different, sometimes diverging, narratives and interests. Frank O. Gehry, the prominent US-American architect, is one of the project's key proponents. He argues that architects can use the technology as a vehicle to return to the architect's mythical origin as

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[12] For an apt review of some prominent such practices see Elite Kedan, *Provisional: Emerging Modes of Architectural Practice USA*, ed. Jon Dreyfous and Craig Mutter, 1st ed. (Princeton Architectural Press, 2009).

[13] Arto Kiviniemi Mikael Laakso, "The IFC Standard: a Review of History, Development and Standardization," *ITcon Vol. 17, Pg. 134-161, Http://www.itcon.org/2012/9*, 2012, 142, http://www.itcon.org/cgi-bin/works/Show?2012_9.

[14] I use "Building Information Modeling" and "BIM" interchangeably throughout the text.

[15] Charles Eastman cited in Randy Deutsch, BIM *and Integrated Design: Strategies for Architectural Practice*, 1st ed. (Wiley, 2011).

[16] In this context, the term *semantic* is used to characterize the elements of a geometric representation as indexes of other types of information. A BIM element representing a door, for instance, contains meta-data in the form of attributes that describe the object's status as a door, as well as more specific characteristics to the door itself (For example material, cost, etc.). This is understood to be a *semantic* representation. The terms invokes associations to the "semantic web," a concept seeking to construe the Internet as a network of machine-readable, structured data. While distinct, semantic webs and semantic architectural representations share the idea that structured data enables greater control and manipulability of information. For an introduction to the concept of semantic webs see: Tim Berners-Lee, "The Semantic Web," *Scientific American*, May 17, 2001, http://www.scientificamerican.com/article.cfm?id=the-semantic-web.

a master builder, increasing their control over both design and construction.[17] In contrast, some developers and clients see it as a way to reduce the role (and the fees) of the architect in building production, allowing them to have a greater say in the definition of projects. Academics with stakes in the *Building Information Modeling* project seek to disseminate its software and cultures of practice through lectures, courses and research projects.[18] The governments of the US and other countries are producing legislation that seeks to enforce BIM practices and technologies in the Architecture, Engineering and Construction (AEC) industry.[19] Industry consortia have sought to standardize BIM practices and digital formats to facilitate information sharing and reduce interoperability issues between designers, engineers and constructors.[20] Economics researchers have studied BIM's potential to optimize design and construction practices and reduce waste, identifying the main obstacles to the system's wide adoption.[21] Furthermore, a growing body of managerial literature seeks to formalize the best practices for *Building Information Modeling's* implementation in firms.[22] A recent book,[23] for instance, seeks to provide managers with strategies to implement it, contending that *Building Information Modeling* is "10% technology and 90% sociology."[24] I have observed that a persistent trait across these different stories is the trope of centrality and periphery, locating the technology of *Building Information Modeling* as a center around which all other practices develop.

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[17] See for instance: David Sheff, "Interview: Frank Gehry," *Davidsheff*, January 2011, http://www.davidsheff.com/Interview__Frank_Gehry.html.

[18] See, for instance Eastman, "Was Alberti Wrong? The Separation Between Architectural Design and Construction." Also, Andrew Witt, "Concurrent Design" (presented at the Forward Talks, Harvard University Graduate School of Design, November 7, 2011).

[19] A report by Prince Charles Kwabi shows how in the US, the National Institute of Building Science created a charter and set in motion a National BIM Standard *Project* Committee in 2005 to deal with standards and trends of the BIM framework in the country with the flexibility of incorporating developments from ISO (NIBS, 2012). Similarly, in the UK, the Government Chief Construction Advisor suggested a roadmap and strategy for progressive use of BIM in government projects plus the need to rise to the BIM challenge through training and support. As a result, the UK Cabinet Office disseminated in May, 2011 the "Government Construction Strategy" that indicated the collaborative use of BIM on its building programs by 2016 (BIS, 2011).

[20] See Appendix for a detailed account of the standardization efforts of governments and industry consortia.

[21] The research by Laakso, Howard, Bjork is a rigorous example of this approach. See, for instance, Mikael Laakso, "The IFC Standard: a Review of History, Development and Standardization." Also, Rob Howard and Bo-Christer Björk, "Building Information Modelling – Experts' Views on Standardisation and Industry Deployment," *Advanced Engineering Informatics* 22, no. 2 (April 2008): 271–280.

[22] For academically rigorous managerial discussions of *Building Information Modeling* see Shiro Matsushima, "Collaboration in Architectural Design: An IT Perspective" (Doctoral, Harvard University, 2003). See also Carlos Andres Cardenas, "Modeling Strategies | Parametric Design for Fabrication in Architectural Practice" (HARVARD UNIVERSITY, 2008), http://gradworks.umi.com/33/18/3318234.html.

[23] Deutsch, BIM *and Integrated Design*.

[24] Industry handbooks for managers often represent social relations as arrows and boxes within flow charts. This representational idiom presupposes social actors as self-standing components of a larger *thing* called practice. Latour has discussed this sort of representation of the social as a material, observing how these narratives imagine the social as "a specific kind of ingredient that is supposed to differ from other materials." I adopt instead his suggestion that "the social seems to be everywhere and nowhere in particular." See Bruno Latour, *Reassembling the Social: An Introduction to Actor-Network-Theory* (Oxford University Press, USA, 2007).

My intention is not to suggest that such accounts are flawed, or devoid of intellectual value because of the commercial interests they may sometimes pursue, or the managerial impulses they may express. On the contrary, throughout this study they are treated as valuable sources of evidence about the ongoing constitution of technology as the central trope of architecture production. I observe, however, how narratives about technology made by its own developers or stakeholders often present desired outcomes as factual accounts. Following Suchman, I take these narratives about design and technology to constitute instead "propositions for a geography within which relevant subjects and objects may claim their place."[25] I contend that the geographies of work inscribed in the technological discourses of design in the *Computer-Aided Design* and *Building Information Modeling* projects play a key role in shaping general and disciplinary expectations about practice —and are thus worthy subjects of serious discussion and debate.[26] We inhabit the worlds we imagine.

MIT as a site

Relevance

As an institution globally branded as a beacon of innovation and technology, MIT occupies a central location in what Suchman calls "the future of everywhere," and, by virtue of this centrality, a space where the meanings of technology and design are constantly negotiated, redefined, and broadcast to a variety of global audiences.[27] Moreover, as I show in the chapters below, the history of the technologies for computational representation —including the cathode ray display tube, the first computer graphics software, the technology for perspective encoding— is tied to the Institute's vibrant post-war era culture of research and development. Thus the MIT archives and the MIT Museum were crucial sources of archaeological evidence of the ideas that shaped design discourses in the early days of the information age.

Given the questions driving my research project, my seven-year experience as a graduate student at the MIT School of Architecture —the courses, lectures, reviews, talks, discussions with faculty and fellow researchers, some of whom seemed to share a *live* connection to the earlier histories of computation— are invaluable sources of research insight.

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[25] I borrow this phrase from: Lucy Suchman, "Anthropological Relocations and the Limits of Design," *Annual Review of Anthropology* 40, no. 1 (2011): 1–18.
[26] Building on Suchman's metaphor, this dissertation can be thought of as a cartography of the imagined geographies of work inscribed in *Computer-Aided* and *Building Information Modeling* discourses.
[27] Suchman, "Anthropological Relocations and the Limits of Design."

Data

During the course of my archival research I had access to the original files of the *Computer Aided Design Project* in the MIT archives. These included the 12 technical reports issued during the project's timeline, as well as several masters and doctoral theses, theoretical papers, numerous memoranda and support documents explaining the details of the technologies developed. These included programming languages, compilers, mathematical techniques for the geometric representation of free-form surfaces, hardware and graphics interfaces —for an estimate total of over 250 documents. Moreover, the MIT Museum gave me access to a collection of press releases, personal files, photographs, letters and artifacts from their collection.[28] In my analysis, I treat these materials as vestiges of what I posit as the earliest computational design culture. The objects and texts I present as part of my analysis to support my thesis here are a small selection of the materials reviewed.

Gehry Technologies as a site

Relevance

Gehry Technologies originated as a small computational team embedded within *Gehry Partners* —the office of the prominent Canadian-born American architect Frank O. Gehry— implementing technologies to aid in the description of the unconventional shapes of Gehry's buildings. The team's adaptation of the aircraft design 3-D software system *CATIA*[29] into their signature software system *Digital Project*, allowed an unprecedented level of precision in the description of 3-D surfaces, expanding the role that digital representations played in design documentation and construction. Their key role in the construction of some of Gehry's most ambitious designs (in particular the Bilbao Guggenheim Museum in 1996) gained for the firm a prominent place in industry as technology innovators.[30] Since its constitution in 2000, the company has evolved into a global consultancy firm separate from *Gehry Partners,*[31] offering technology services to design and construction clients around the world (including, but no longer limited to, *Gehry*

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[28] I was able, for instance, to physically hold one of the hand-woven memory panels of the TX-2 machine where the first graphics software, the *Sketchpad*, was programmed. I am indebted to Theresa Smith at the MIT museum for going out of her way to give me access to these materials.

[29] This was the result of a partnership, started in 1996, between Gehry's office and the French Aero-space company Dassault Systems.

[30] See, for instance, Laurence B. Chollet, *The Essential Frank O. Gehry*, 2001. and Kedan, *Provisional.*

[31] *Gehry Technologies's* constitution was a result of the convergence of different factors. Saliently, the kind of managerial and technical work enabled by their use of software started to exceed the contractual boundaries of an architectural practice, making it a legal necessity to separate the two organizations. More on this in Chapter 4.

Partners).[32] As an internationally distributed company, each regional office has a specialized profile within the larger scope of the firm, shaped by the needs of its local market. The Middle East branch located in Abu Dhabi —where I did my fieldwork— concentrates on the use of *Building Information Modeling* as a system of project coordination.[33] I thus had access to a culture of practice distinctively shaped by concerns about the immediacy of building, the multi-disciplinary organizational complexity of large projects, and the scientific-managerial ethos of increasingly globalized contemporary design and building practices.

The unique relevance of *Gehry Technologies* to my project lies in its prominent role in shaping the AEC[34] industry's expectations about technology and software. The Middle East office offered a uniquely rich site to observe and participate of the technological and organizational challenges of implementing BIM as a design and construction coordination tool. These challenges were amplified by the cultural and linguistic diversity of Abu Dhabi's competing cultures of representation, construction, and work. [35]

Data

The single most important source of empirical data about *Building Information Modeling* was an 11-month long period of fieldwork in Abu Dhabi, between October 2010 and September 2011. During this period I was both a Project Consultant and a researcher at the regional office of *Gehry Technologies*. As a Project Consultant, I was part of the *Building Information Modeling* coordination team for several projects. My roles included technical and administrative responsibilities such as BIM coordination, synthesis,[36] computational tool-making and modeling —roughly in that order of importance and time-investment. As a researcher, I engaged in the qualitative research tradition of participant observation,[37] adopting and

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[32] The company's portfolio has grown to include many high profile architecture commissions by some of the world's most renowned architects and engineers.

[33] Other offices have slightly different profiles. The Paris office, for instance, collaborates closely with architecture studios during the design stages in processes of geometric "rationalization." The Hong Kong office deals mostly with the complex process of MEP modeling and coordination. The Los Angeles office works heavily on Gehry and Partners' projects. During the period of my fieldwork, the research and development efforts of the organization shifted focus from the development of their signature software *Digital Project,* to the development of web-based applications for building information sharing and coordination.

[34] Architecture, Engineering and Construction.

[35] The practice of Gehry Technologies is itself changing quickly. From a reliance on their signature software *Digital Project*, the company is shifting towards their own cloud-based services of project information management capable of better centralizing information exchange around a single digital representation of a building, consolidating the trajectory of technological centrality and universality I identify above.

[36] Synthesis refers to the collection, compilation and evaluation of 3-D models from different organizations in a single digital (BIM) model. Chapter 7 discusses this in more detail.

[37] I further discuss this approach to method in the next section.

active technical role within the organization. I thus had access to the culture of practice developing in and around the *Building Information Model* at *Gehry Technologies* and other participating companies.[38]

A large portion of my data comes from ethnographic field-notes taken during or immediately after dozens of informal interactions, meetings and conversations with project managers, architects, engineers, subcontractors of different trades, draftsmen, coordinators and software developers. While many notes, especially those at the beginning of my fieldwork, were taken following strict protocols of fieldwork research, a considerable portion of the insights shaping this report are bits and pieces of evidence recorded or simply kept in less structured ways: sentences scribbled in the margins of a printed piece of paper, informal conversations with colleagues while drinking coffee, exchanges happening when recording devices were unavailable or simply off. Additional sources of data are more than 20 non-structured ethnographic interviews, lasting between 1 and 3 hours, which I conducted with BIM proponents, engineers, architects, software developers, consultants, and coordinators, who knowingly engaged me as a researcher. In these interviews, I sought access to each subject's conceptualizations of software, design, and work, in relation to their everyday practice. Rather than summarizing the contents of the interviews, I select moments I deem illustrative of the reconfigurations of design and technology concerning this study.[39] A last source of data is the flow of digital information around the coordination process itself. To capture it, I developed custom software that recorded, normalized and visualized detailed information about design and construction conflicts reported by BIM coordinators during 4 months. The data-collecting software was introduced in the coordination files of a team of BIM coordinators who knowingly agreed to the experiment.[40]

Limitations of the study

Involvement

My dual role as both a researcher *and* consultant may be construed as a source of conflict, disadvantage, and compromise. While this risk existed throughout my fieldwork, its potential effects on my data-

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[38] Members of *Gehry Technologies*, as well as key members of the other organizations, were aware of my dual role as consultant and researcher. In my account, I work to ensure the anonymity of the subjects when they so requested, and the confidentiality of the projects' particular information. For instance, the names of projects, actors and companies, have been transformed to protect both the identities of the subjects and the confidentiality of the organizations.

[39] Some of the interviews were given under condition of anonymity. In these cases I use a pseudonym, and indicate so in the text.

[40] I discuss this in more detail in Chapter 7.

collection and analysis are mitigated by constant self-analysis and discussion with academic advisors.[41] In turn, my first-hand involvement with *Building Information Modeling* practice at *Gehry Technologies* provided me with the irreplaceable opportunity to engage with the social and technical textures of every day practice.[42] I adopted as method the qualitative research tradition, common in anthropology, of participant observation —in which the researcher takes up a role in the culture under study. The key advantage of participant observation over other forms of qualitative research is that it enables the researcher to bypass prepared verbalized constructions subjects often use to represent themselves in formalized encounters — such as interviews or surveys. Participant observation thus uniquely enables the researcher to contrast received narratives about —and abstract representations of— practice with the realities on site. Moreover, by sharing the everyday challenges of coordination with my subjects, I was able to learn their languages, understand their way of life, and study their primary texts: the Cartesian, interactive digital interfaces of *Building Information Modeling* software.[43]

Also important, the sharp contrast of this (professional, urban and geographical) environment with my previous experiences[44] heightened the sense of displacement and "exile" that anthropologists understand to be key to effective observation. Sherry Turkle, for instance, describes this displacement with the anthropological notion of *depaysement:* the process through which "one leaves one's own culture to face something unfamiliar, and upon returning home it has become strange —and can be seen with fresh eyes."[45] In my study, the notion of *depaysement* (literally "to de-countrify"), applies also to the process of adventuring to new conceptual and technical territories —while learning something new about my own familiar domains.[46]

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[41] Also important, the risk of compromising my role as a scholarly observer was mitigated by an open and generous attitude towards the potential value of the research by Gehry Technologies' leaders and colleagues.

[42] As a methodological guideline I appropriate Geertz's famous explication of the analysis of culture: "Believing, with Max Weber, that man is an animal suspended in webs of significance he himself has spun, I take culture to be those webs, and the analysis of it to be therefore not an experimental science in search of law but an interpretative one in search of meaning. It is explication I am after, construing social expression on their surface enigmatical" C. Geertz, "Thick Description: Toward an Interpretive Theory of Culture," *Culture: Critical Concepts in Sociology* (1973): 173–196.

[43] I was not a complete outsider. My MIT education in different forms of technological practice had prepared me well for these challenges.

[44] Given my architectural background as a computational designer, encountering a culture so engaged with the everyday challenges of design and construction coordination was a very difficult —yet very rewarding— experience.

[45] See Turkle, S. (2005). *The Second Self: Computers and the human spirit (20th anniversary edition).* Cambridge: MIT Press.

[46] From this perspective there are similarities between the notion of "depaysement" and Schon's notion of "reflective practice." In "The reflective practitioner" Donald Schon sets in motion a way of understanding professional practices as reflective dialogues with the materials and tools that participate in a process. In a similar vein, design theorist George Stiny conceives design as an iterative process of perception and action, of seeing something as new each time. Stiny's conception of embedding presupposes that a form of "micro-depaysement" is the basic building block of design.

Scope

My portrait of *Building Information Modeling* is limited to a very specific context of practice. While I bring into my analysis references to the broader project of BIM through a variety of historic and experiential materials, my main ethnographic site is bounded geographically, institutionally and technically, to the UAE context of architecture production and the *Gehry Technologies* culture of practice in the period between 2010 and 2011.

Likewise, my study of early computational design discourses is bounded institutionally and geographically to MIT and the expanded *Computer-Aided Design Project*, a research operation active between 1959 and 1967 —yet with direct consequences, as I show, reaching the mid-seventies, and indirect —as I will show— to our days.

The aim of my study thus is not to provide a comprehensive account of either the BIM or CAD projects in a global, regional, or disciplinary sense. Instead, my study must be seen as an example of *meso-scopic* research, a phrase that historian of science Peter Galison coined to refer to the study of subjects and sites whose research value depends less on their ability to describe a general condition, and more on their capacity to become vehicles to understand large processes through particular instances. In this case, the larger process I observe is the ongoing standardization and informatization of practices via computerization, and its effects on the conception and production of the built environment. Because the earliest developments in computer graphics can be traced to MIT, and Gehry Technologies' role in the contemporary convergence of technology and design, both my sites are beacons expected to continue exerting an important influence on the contemporary constitution of technology and design discourse.[47]

Chapter Outline

In Chapter 2, I review historical and sociological accounts of architectural practice. In my analysis of these accounts, I highlight the shifting physical and discursive distance between architectural and construction practice. I consider this distance as constitutive of the architect's disciplinary identity. Drawing on the histories of professionalization by Johnston,[48] Woods[49] and Gutman,[50] I explore the

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[47] Other researchers have shown the influence of of information theoretical idioms on design discourses outside the US. See in particular Alise Upitis's study of British design pedagogy during the post-war era, "Nature Normative□: the Design Methods Movement, 1944-1967," Thesis, 2008, http://dspace.mit.edu/handle/1721.1/45943?show=full.

[48] George Barnett Johnston, *Drafting Culture: A Social History of Architectural Graphic Standards* (The MIT Press, 2008).

[49] Mary N Woods, *From Craft to Profession: The Practice of Architecture in Nineteenth-Century America* (Berkeley: University of California Press, 1999).

[50] Robert Gutman, *Architectural Practice: A Critical View*, 5th ed. (Princeton Architectural Press, 1997).

organizational reconfigurations of the US-American architectural office during the 20th century. In these stories of practice, I highlight the role of scientific-managerial ideologies —informed by the proven efficiencies of the war effort— in transforming the subdivision of labor —and the culture of architectural practice— within firms. I review the critical voices of Larson,[51] Ghirardo[52] and Cuff,[53] who argue against the autonomy of architecture's academic discourse, advocating an expanded understanding of building production as a contingent social practice. I use these accounts to situate my inquiry into contemporary design and building practice within the context of an ongoing conversation about the role of the architect in the production of the built environment.

In Chapter 3, I draw from archival materials of the *Computer-Aided Design Project*, a research operation funded by the US Naval Forces at MIT between 1959 and 1967. I discuss the project as an "ecology of knowledge" that redefined conceptions of design, representation and materiality. In my analysis of these early discourses of computational design, I identify the emergence of a new representational tradition based on the structured combination, in the computer, of perspective geometry and data processing. I show how the *encoding* of perspective and the subsequent constitution of the computer as a universal representation machine, facilitated an expansion of scientific-managerial themes of technological centrality and control in discourses about design and construction. By situating Nicholas Negroponte's techno-social proposition within this context, I illustrate the links between the MIT techno-militaristic project —and its associated academic enterprise— and the constitution of new forms of architectural thinking in the US-American post-war era. In my analysis, I argue that Negroponte's proposition for a technologically enabled participatory design fails as a critique because of the deletion, in discourse, of the machines' complex ties to its makers. I further discuss how key aspects of the technological and discursive repertoire Negroponte introduced into architecture, stem from a larger intellectual and institutional context of knowledge production at MIT.

In Chapter 4, I consider the paradigms of design and interaction driving commercial software applications for architecture and design. I then introduce the *Building Information Modeling* project through the encounters with three of its more important proponents. In my analysis of their discourses, I identify long-standing desires about the centrality and universality of technology, and draw parallel lines with the seminal discourses of design set forth by the MIT computer pioneers. I consider this ambition of centrality and universality as the expression of an imperial impulse that manifests itself as an urge, in computer

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[51] Magali Sarfatti Larson, *Behind the Postmodern Facade: Architectural Change in Late Twentieth-Century America* (University of California Press, 1993).
[52] Diane Ghirardo, ed., *Out of Site: A Social Criticism of Architecture* (Bay Pr, 1991).
[53] Dana Cuff, *Architecture: The Story of Practice* (Cambridge, Mass: MIT Press, 1991).

cultures, to reinvent the sites of design and construction practice in the computer's language, and image.[54] One of the immediate effects of the reconfiguration, I argue, is the de-stabilization of a crucial narrative in architecture about the primacy of design over construction.

In Chapter 5, I consider how the socio-technical practice of BIM and the socio-geo-political landscapes of Abu Dhabi are related. To delineate the larger socio-political context of Abu Dhabi, and the place architecture occupies in it, I draw from anthropological and historical accounts of the UAE,[55] as well as from recent works in the social sciences that have approached critically the effects of globalization on architectural practice. I use these accounts to provide a context for my observations of the design and building production in Abu Dhabi. I consider how my subjects confront and make sense of the larger social and political frames in which their practice is embedded.

In Chapter 6, I explain the *Building Information Modeling* project from the field in relation to the claims, advanced by its advocates, of technological centrality and universality —in other words, of technology's capacity to become a *lingua franca*[56] across design and construction. Drawing on ethnographic observations collected during one year of fieldwork, I discuss how competing cultures of representation and work interact during the design and construction coordination of two projects, critically examining the claims to centrality and universality of BIM in the light of its practice. Through ethnographic accounts of different subjects' encounters with BIM, I show how the infrastructure of *Building Information Modeling* is contested at every step by organizational, contractual and legal cultures of practice. Lastly, I consider how architects perceive themselves, and their discipline, in relation to their roles in this particular context. I conclude my ethnographic portrait by discussing an experiment in software-driven observation. Drawing on detailed data about design and construction conflicts reported by a team of four BIM coordinators, and collected automatically by a custom software I programmed, I present an interactive data visualization tracing the flows of information between different individuals and organizations over four months of a project's design and construction. I use this tool to explore aspects of the complexity of the BIM coordination process, and interrogate interactive data visualizations as tools of cultural analysis and reflection.

In Chapter 7, I summarize the study, re-specifying technological systems as infrastructures —not as "tools," or "instruments"— for the production of the built environment. As infrastructures, technological systems can only be partially addressed by existing historical or socio-anthropological accounts of architectural practice, and thus demand expanded forms of criticality.

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[54] A similar argument is drawn by Philip Agre, "Toward a Critical Technical Practice: Lessons Learned Ni Trying to Reform AI," in *Social Science, Technical Systems and Cooperative Work* (New Jersey, London: Lawrence Erlbaum Associates, 1997), 131.

[55] In particular Ahmed Kanna, *Dubai, the City as Corporation* (Univ Of Minnesota Press, 2011). Frauke Heard-Bey, *From Trucial States to United Arab Emirates: a Society in Transition* (Longman, 1982). And Deyan Sudjic, *The Edifice Complex: How the Rich and Powerful Shape the World*, Edition Unstated. (Penguin Press HC, The, 2005).

[56] A common language.

In the Appendix, I include supporting materials. Among these, an essay outlining alternative imaginations of technology in design, a detailed review of the history of *IFC* standardization, and the JAVA/Processing code developed for the data-visualization.

2. ARCHITECTS, A BRIEF SOCIO-HISTORICAL REVIEW

The architect's authority

Outline

Culturally dominant narratives about architecture portray it as an individualistic creative practice devoted to the envisioning of buildings endowed with cultural and artistic value, sometimes to the expense of functionality or common sense.[57] These narratives rest on a diverse set of historical, epistemological and ideological supports —crucially, on an evolving social, physical and epistemological distance from materials and labor identifying the architect's professional identity in opposition to the drudgery of working with materials. Throughout this chapter I will consider historical and sociological accounts of architectural practice, highlighting the role of building representations —such as drawings and computer models— as both expressions and mediators of this distance, allowing the world of construction and materials to be constructed, in the ideological edifice of academic architecture, as "lower" forms of practice.

The authority of the written word

The earliest surviving document about architecture is the 20 BC treatise "De Architectura," in which the Roman architect Vitruvius explicitly claimed to be writing "the body"[58] of the discipline. Vitruvius's crucial proposition stated that the architect should rise above construction and create buildings with "firmness, commodity and beauty."[59] Crucially, the architect's authority[60] *(auctoritas)*, emerged from the

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[57] The figure of the "starchitect" is an example of how popular media celebrates an imaginary of fame and individual prowess —similar to that of artists or athletes— for (certain) architects. Woods observes how this image of the architect as an individual force is synthesized in the figure of Howard Roark. Woods, *From Craft to Profession.*
[58] As observed by Indra Kagis McEwen, *Vitruvius: Writing the Body of Architecture* (The MIT Press, 2002).
[59] To do so, the Vitruvian architect had to be a cultured individual. Vitruvius famously identified nine fields of knowledge the architect should be acquainted with: "He should know writing, be skilled in drawing and trained in geometry. He should be able to recall many stories, listen carefully to the philosophers, not be ignorant of medicine, know music, remember the responses of jurisconsults, and be well acquainted with astrology and the order of the heavens." Ibid.

mastery of both materials *(fabrica)* and the written word (*ratiotinato*). By articulating and systematizing work, writing gave authority to both architecture and the architect. [61]

> Architects who aim at employing themselves with their hands without the aid of writing will never be able to achieve authority equal to their labors. Those who rely only on discussion and writing will look as if they had chased a shadow and not the thing itself. But those who have mastered both, like men fully armed, will attain their goal speedily and with authority.[62]

Scholars' accounts of architecture in the Middle Ages depict a retreat of the architect as the Vitruvian *learned man* and a "return" to building practices controlled by groups of artisans, builders, and master masons. An example is David Turnbull's argument that the construction of gothic cathedrals was the result of a messy, largely unstructured social and verbal interaction between masons, clients and artisans —he calls these collectives "living laboratories"— instead of individual masterminds.[63] Gothic construction consisted, under this view, of itinerant groups of masons, traveling from project to project, carrying building templates,[64] skills, and tacit knowledge about construction, to the next project.[65]

The authority of drawing

Most scholars agree that the architect as an authorial figure —a learned man on whose shoulders rested the responsibility for the whole building— re-surfaced in Italy during the fifteenth century. During this period, as Magali Larson recounts, a new wealthy merchant class demanded buildings with a "new sense of monumentality,"[66] and so gifted artisans were given the chance of commanding the efforts of builders and other artisans. Despite being inevitably dependent on the collective effort of many skilled people, works of architecture received the status paintings and sculptures enjoyed as works of individual artistry. Moreover, endowed with artistic credentials, architects were allowed access to the spheres of power

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[60] McEwen discusses the etymological origins of *auctoritas* in the context of Vitruvius' treatise: "Auctoritas was an endemically Roman notion. Originally a legal term related to vouchshafing and guaranteeing, authority was the security offered by an *auctor* who underwrite an action undertaken by someone else. A contractual matter in the legal sphere and, analogously, in the politico-religious one, *auctoritas* entailed trust, mutual obligation, and good faith: wat the Romans called *fides*." Ibid., 33.

[61] Catherine Ingraham makes a related point suggesting that the wide knowledge of the architect is key to "assist in the telling of certain stories in architecture that, in turn, authorize the building of certain buildings." See Ms Catherine Ingraham, *Architecture and the Burdens of Linearity* (Yale University Press, 1998), 13.

[62] Vitruvius, cited in McEwen, *Vitruvius*, 33.

[63] Turnbull, *Masons, Tricksters and Cartographers.*

[64] Templates were used by stonecutters as aids in their work.

[65] This view is contested by scholars who argue there is sufficient evidence of drawings from this period to identify a social role similar to that of the modern architect. See, for instance, Mario Carpo, *The Alphabet and the Algorithm*, 1st ed. (The MIT Press, 2011), 17.

[66] Larson, *Behind the Postmodern Facade*, 3.

denied to artisans and builders. If during Vitruvius' time architects had identified the written word as a crucial rationalizing and systematizing device—and as a warranty of the architect's "auctoritas"—it was during the Renaissance that graphical descriptions emerged as the foundation of the discipline's claim to legitimacy and social status. The period's most important architecture treatise, Leon Battista Alberti's "De Re Aedificatoria" ("On the Art of Building"),[67] famously established the distinction between *lineamenta* and *structura. Lineamenta* referred to the building's representation —specifically the ground plan— a domain in which "all the ideas of the architect are incorporated"[68] whereas *structura* referred to the construction of the building—a task to be undertaken by a "skilled craftsman." Alberti's distinction between a mental sphere —the sphere of the architect's reasoning, closely tied to the visual— and a physical sphere is consistent with a western tradition of elevating the mental over the material, of contrasting the plasticity of thought to the, so to speak, *brittleness* of matter.[69] A crucial innovation of Alberti's time was the mathematization of representation consequence of the adoption of perspective representation.

In the anthropocentric worldview of the Renaissance that "opposed matter and spirit"[70] command over geometric representation played a crucial role in establishing the architect's authority over the work of stonecutters, masons, carpenters and sculptors. In his analysis of architecture's historical relationship to geometry, architect and historian Robin Evans[71] shows how French stonecutting treatises, or *traits*, [72] were the source of social tensions between masons and architects and in fact played a role in their split.[73] Evans suggestively describes how, for architects, representations of geometry allowed architects to move across numerous boundaries, between "the corporeal and the incorporeal, the absolute and the contingent, the ideal and the real."[74] The preeminence of abstract representations over materials and labor[75] was a crucial factor that facilitated the architect's claim of a higher social status, and defined the modern contours of the discipline. But besides the disciplinary focus on representation, organizational needs played a role in the constitution of the modern role of the architect above materials and labor.

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[67] Leon Battista Alberti, *On the Art of Building in Ten Books*, trans. Joseph Rykwert, Neil Leach, and Robert Tavernor (The MIT Press, 1991).

[68] S Lang, "De Lineamentis: L. B. Alberti's Use of a Technical Term," *Journal of the Warburg and Courtauld Institutes* 28 (1965): 331–335.

[69] Alberti's role as a Renaissance scholar and architect is an early precedent —yet distinct— of the "gentleman architect" that would appear later in England during the second half of the seventeenth century. However, Alberti's distinction between construction and design must be read keeping in mind that at his time the modern social role of the architect did not exist.

[70] Robin Evans, *The Projective Cast: Architecture and Its Three Geometries* (The MIT Press, 2000), 38.

[71] Evans, *The Projective Cast.*

[72] Evans defines traits as "layout drawings used to enable the precise cutting of component masonry blocks for complex architectural forms, specially vaults." Ibid., 179.

[73] Evans narrates beautifully the partnership between Bosse, an artist and engraver, and the architect Desargues, in developing techniques for visually representing stone cuts. Ibid., 204.

[74] Ibid.

[75] Catherine Ingraham called this preeminence, suggestively, one of architecture's "burdens of linearity." Ingraham, *Architecture and the Burdens of Linearity*.

The authority of the manager

Historian of construction Jacques Heyman locates the split between the master builder and the architect in the figure of Christopher Wren, a professor of astronomy in seventeenth century England.[76] Wren had no experience as a builder and, in contrast with architects trained in workshops as apprentices, had acquired his architectural knowledge studying salient buildings in a trip to Paris. The great fire of 1666 in London destroyed a large portion of the city, and Wren's firm was in charge of their reconstruction. Faced with a challenge of such an unprecedented scale, Wren adopted a *managerial* role which, simply put, consisted of the coordination of other practices as "contractors."[77] Heyman argues that the organizational innovation of Wren and Partners constitutes the earliest documented example of architect's modern role as a coordinator of trades, and as a bridge between clients and builders.[78]

Architects in the United States: a special case

An old profession in a "new world"

The US offered a different context for architectural practice. While British architects enjoyed the patronage of the state through public commissions that helped sustain the quasi-aristocratic image of the profession, in the early history of the profession in the United States, those who aspired to the status of "gentleman" architects had to struggle to distinguish themselves from building mechanics and other practitioners who represented themselves as architects.[79] In her study of architects' struggle for professionalization in the nineteenth century United States, Mary N. Woods locates the earliest expressions of architecture's transition from craft to profession in the antebellum period—between 1820 and 1860—in men who had been trained in building workshops or architectural offices at the start of the century.[80] Such figures "defined the professional architect as a designer and supervisor standing between

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[76] Jacques Heyman, "Wren, Hooke and Partners," in *Proceedings of the First International Congress on Construction History* (presented at the First International Congress on Construction History, Madrid: Instituto Juan de Herrera, Escuela Técnica Superior de Arquitectura, Madrid (Spain), 2003), 3–9, http://en.structurae.de/refs/items/index.cfm?id=r0004553. I also discuss Heyman's take on Wren in Cardoso Llach, "A Generative Grammar for 2D Manufacturing of 3D Objects."

[77] Heyman, "Wren, Hooke and Partners."

[78] Ibid.

[79] Woods, *From Craft to Profession.*

[80] For Woods the lack of strong class distinctions that characterized America since the colony relative to Europe shaped the origins of practice, making it hard for "gentleman" architects to be regarded as their client's peers. Woods traces the tension between the gentleman and the "practical" architects in America back to the figure of Benjamin Henry Latrobe—the architect of the Capitol—an educated architect who migrated from England in 1796.

the clients who commissioned the work and the artisans who constructed it"[81] and "recognized that a few isolated practitioners, however gifted, could not transform architecture from craft into a profession. They experimented with partnerships and large offices as new forms for architectural practice."[82] However, it was not until the formalization of academic training and the constitution of professional associations during the second half of the nineteenth century that architects were able to establish a distinct social and professional status. Accounts of US-American professionalization highlight the role that a generation of architects trained in the Parisian Ecole de *Beaux-Arts* played in the struggle for architecture's professional legitimacy. This generation, which included Richard Morris Hunt, Henry Hobson Richardson, Daniel Burnham, and Dankmar Adler, sought to combine professional practice and instruction following the model of the French atelier —a collective space run by students who compose projects under the direction of a patron.[83] These architects were the first to initiate professional associations and the writing of the licensing laws that regulated access into the profession. The firms of Richard Morris Hunt and Henry Hobson Richardson were both places of instruction and practice,[84] and exerted great influence in the first formal training programs in architecture.[85] In fact, the first of such programs (MIT's) was first headed by one of Henry Morris Hunt's employees, Robert Ware, in 1865.[86] Ware's vision was that MIT would train draftsmen to feed the professional firms:[87]

> ... The primary aim of the new program at MIT at its outset was not the education of architects per se, but rather the education of architectural draftsmen whose competent exercise of technical judgment in matters of everyday practice would be an aid to architects in the pursuit of their art and business and would help to raise the overall quality and repute of the profession.[88]

At the same time, however, he was sharply aware of the role academia could play in the architecture's struggle for a higher social standing.

> The profession is, at present, in the hands of mechanics, many of whom are first-rate; of contractors and super-intendents, who are mechanics with a talent for

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Latrobe proclaimed himself "the first professional architect and engineer to practice in the US" and complained profusely about the profession's lack of social standing. Ibid., 7.

[81] Woods, *From Craft to Profession.*

[82] Ibid., 5.

[83] Very much like architectural studios today.

[84] Johnston, *Drafting Culture,* 33.

[85] The commitment to the ideal of architectural practice was so strong that in fact the programs shedded any commercial connection of the architect to the project. This allegiance to self-lessness was perceived by many architects to be a part of the AIA code up until the 1970s, as Robert Gutman shows in Gutman, *Architectural Practice,* 47.

[86] MIT was also the first architecture school in North America.

[87] Draftsmanship was the necessary "entry" to the profession.

[88] Johnston, *Drafting Culture,* 33.

> affairs, and many of whom take the name of architects; of architects proper, few of whom have an adequate training in the higher branches of their calling.[89]

Ware favored a "learning by doing" approach —that still resonates at the MIT School of Architecture and Planning as a guiding pedagogical narrative.[90] The appearance of architecture programs like MIT's within US-American universities during the second half of the nineteenth century was effective in raising the social and professional status of their alumni above those who obtained their credentials in mechanics schools, or in night schools.

Class tensions and the corporatization of practice

Academically trained architects with knowledge of history and theory, and endowed with artistic aspirations, were, according to Johnston, "indoctrinated into an elite and often elitist culture of architectural design"[91] that carved them a professional and social space apart and above the "practical architects" and the contingencies of materials and labor.

During the first half of the twentieth century the increased use of mass-produced standardized materials such as steel and glass demanded increased precision, detail and volume in building's documentation, prompting organizational changes in the architecture office as well as an increase of its size. Some architects, like Herbert Kenway from Boston, would find enough clients to develop successful practices (See Frame).

> "My great-grandfather Herbert Kenway was an architect who was trained in the UK (he was from Wales himself) and who moved to the Boston area as a relatively young man. He married a woman from a Boston family (with abolitionist roots, but that is another story) and they had four children together in the 1880s, living in Newton, as he developed his practice. This became a firm called Allen and Kenway which did houses in the Back Bay and suburbs, as well as projects like the Newton High School. Kenway died at the early age of 39 in 1890 (cancer? no one is sure) and now lies in Newton Cemetery along with his wife and two daughters. At one point I was showing his early sketch book, from his years in the UK, as well as some other materials I inherited (including a big collection of Ruskin's works!) to Margaret Henderson Floyd, a historian of Boston architecture (who died in 1997). She commented, "It is quite an accomplishment to have done so much work at such an early age." At that time the age of 39 seemed not so young to me, so I said to her, in so many words, "39 is not *that* young, is it?" Her response is what I have remembered so well: "In

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[89] Ibid.

[90] This approach was, according to Johnston, connected to the "American context of manual training and shop-based education."

[91] Johnston, *Drafting Culture.*

> architecture that is young, because in that profession people are entrusting you with a lot of money. They do not like to do this with young people, and this is why many architects don't really get traction until they are well into middle age." Or again words to this effect. It's the "people entrusting you with a lot of money" that seemed then and seems now to explain so much about this 'art[92].'"

But for most academically trained architects the artistic aspirations instilled by the *Beaux-Arts* system came into conflict with the less glamorous reality of practice. Many of them saw that long years of draftsmanship in an office were not a guarantee towards professional status as architects, realizing they would spend most of their careers as employees of others. Such strongly hierarchical context, which was familiar for engineers,[93] was difficult for architects to accept given the aspirations of individual artistry instilled in them during their academic training. As a result, tensions emerged between architects and draftsmen who resented the lack of upwards mobility in the profession. The tensions were accentuated in the period following the First World War, as all sectors of the US-American economy were under pressure to incorporate ideas of scientific management into their practices, bringing a key aspect of the wartime's ideology into the marketplace.[94] While not all in the profession were equally enthusiastic about the changes,[95] the metaphor of the factory and of the military became a common way to think about the architecture office. Engineering, often seen by architects as antagonistic to creative work, became a model for the architectural office. The incorporation of scientific management ideas into architecture firms resulted in an increased specialization of its members, which made the social and economic barriers that prevented draftsmen from becoming architects more difficult to surpass, prompting concerns about the employee's alienation.[96] The age of the corporate architecture office had begun.[97]

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[92] From a private exchange of the author with Rosalind Williams.

[93] For a history of engineering in America see David F. Noble, *Forces of Production: A Social History of Industrial Automation* (Oxford University Press, USA, 1986). Also, see: Matthew Wisniosky, "Engineers and the Intellectual Crisis of Technology, 1957-1973" (Doctoral, Princeton, 2005).

[94] Johnston, *Drafting Culture*, 54.

[95] "While Hamlin warned against the "industrialization" of the architect's office, others seized on the factory and the military as paradigms of order for increasing the effectiveness of architectural production." Ibid., 59.

[96] With the gradual transition of architecture from a vocation to a profession the social distance between architect and draftsman grew. Drafting and Drawing are linked: to move, to drag (a heavy load, but also a precise instrument). Ibid., 2.

[97] "Streamlining tactics included the ordering of business procedures, the specialization of functions within the firm, the weeding out of redundancies, and the elimination of unnecessary motion within the design and drafting departments." Johnston's account of the mentality of this early stage of professional optimization is reminiscent of the ongoing campaign about optimization via BIM. Ibid., 59.

"Design" as a space of power and privilege

New rhetorical devices played a role in the professional demarcation of architecture: the modern use of the word "design" appears precisely during this period, as a device for allocating power, and for establishing a social and professional hierarchy between architects and draftsmen. While "designing" was construed as a creative endeavor, "drafting" was construed a "merely" technical, or *mechanical* one. As Johnston observes:

> Where a paternalistic metaphor had made the draftsman an extension of the architect's body, the rhetoric of business organization reduced him to the role of a cog in a machine. The compartmentalization of roles within the architect's office, and the emphasis on increasing efficiency in the drafting room, led to tensions and frictions that were difficult to ameliorate through appeals of fellowship and loyalty.[98]

The organizational reconfigurations of the architectural workplace: the finer subdivision of labor and the consolidation of the architect's social role as a provider of drawings, introduced new social and cognitive distances between the architect and the building site, weakening the "epistemological link between constructions in the field and the drafting board representations."[99] Continuing to nurture artistic aspirations, architectural training almost inevitably focused on draftsmanship and theory, and less on building. As the twentieth century unrolled, the academic training of architects continued to depart from the experiences of a vast majority of practitioners, cultivating an ethos of theoretical and artistic sophistication unconcerned with the practical realities of building.

Between managers and artists

The distinctive flavor the profession acquired in the United States was thus a result of a split professional identity. On one hand the ideological construction of architecture as artistry erected by the *Beaux-Arts* training nurtured an image of the architect as a gentleman, a scholar, and an artist. On the other, the engineering ethos of production and the reality of a competitive marketplace without "patrons" (only "clients"), nurtured an image of the architect as a manager and a businessman —and its flipside, a

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[98] Ibid., 74.

[99] The "epistemological link" is, according to architects, enabled by the architect's understanding of the construction aspects of the drawing beyond mere draftsmanship. A non-linked representation relies on graphism, rather than understanding. See Ibid., 30. In chapter 5 I explore how architects resort to similar forms of professional demarcation in the world of BIM coordination.

"cog" in a corporate machine.[100] For architect and critic Dana Cuff this contradiction plays against architects' interests: "by devaluing the conditions that frame the creative process, a spectrum of constraints and opportunities are overlooked and removed from the potential control of the architect."[101] The focus of architectural training on artistry pulls future professionals away from the concerns of practice, creating false expectations and, in many cases, guarantees professional frustration. As Robert Gutman shows, despite the formalization of education and professional associations, architects' professional space and legitimacy remain contested by other professional groups and economic forces throughout the second half of the 20th century.[102] Larger developing and building contractor companies, capable of managing the whole building process, claim areas of expertise traditionally associated with architecture, contesting the architect's privileged relationship with the client, as well as his or her control over building design and construction.[103] In this scenario, the architect's role is reduced —marginalized to that of a minor player in whole-packaged works that clients hire directly with a main contractor.[104] The ideological construction of the architect as a gentleman, a scholar, and an artist, mostly unconcerned with materials and labor —a legacy of Alberti's— plays against the struggle to reestablish disciplinary authority over building production.[105]

Flash-forward: Gehry's technology

The Canadian-born US-American architect Frank Gehry has referred to the reduction of the architect's responsibilities as a "terrible scenario for architects," in which the architect is "infantilized" by the contractor.

> Until now, you hired an architect and they designed a building you liked. You put it out to bid to contractors and the bid comes in high. You don't have the high. What do you do? You turn to the contractor, who begins telling you how to

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[100] For architect Dana Cuff, "the larger professional project—to achieve unity and standards—was contradicted by curricula intended for personal, non-standardized, artistic development." See Cuff, *Architecture*, 30.

[101] Ibid., 56.

[102] Gutman, *Architectural Practice*.

[103] See Gehry's "Organization of the Artist."

[104] In a 1998 critical study of the practice in the US Robert Gutman quotes a consultant: "...increasingly, through their own actions, architects are running the risk of being treated as design subcontractors. Rather than being the spouse, many architects are becoming like the household chef, respected for technical and artistic talents, but nevertheless part of the downstairs kitchen staff and paid accordingly." See Gutman, *Architectural Practice*, 78.

[105] While practicing architects are well aware of the architecture's collective, negotiated character, popular images of the profession continue to abide by the ideological construction of the architect as an individual force. According to Larson, this constitutes a form of bargain, allowing the profession at large to take credit for the accomplishments of a few —and thus sustain a higher social and cultural status. See Larson, *Behind the Postmodern Facade*.

> cut costs. The contractor becomes parental and [the] architect becomes infantilized.[106]

In Gehry's view, the only way to avoid the infantilization of the architect by the contractor is to fight for what he calls "the organization of the artist:" essentially an organizational move placing the architect on top of the design and construction hierarchy, giving him supervisory control over the all trades.[107] Technology plays a key role in Gehry's ideal form of practice. Referring to one of his projects, Gehry states:

> We were able to build it because computers demystify the complex, so it gives you more freedom. Before we built anything we worked it all out on computers until we knew exactly what would and wouldn't work and how much it would cost. Architects are back in control...[108]

Even though he doesn't know how to use one, Gehry sees computers as empowering devices, allowing architects to reclaim control over the whole project. In a conversation with Bent Flyvbjerg, Gehry explains again the marginalization of the architect, this time with a gender association, invoking the architect's marginalization from the project as a *feminization.*

> There's a tendency to marginalize and treat the creative people like women are treated, 'sweetie, us big business guys know how to do this, just give us the design and we'll take it from there.' That is the worst that can happen. It takes the organization of the artist to prevail so that the end product is as close as possible to the object of desire that both the client and the architect have come to agree on.[109]

In Gehry's view, technology —in the form of computer modeling systems— turns the feminized artist into a man (a father) again. The 3-D interactive interfaces of *Digital Project*, Gehry's signature software, are the *traits*[110] that re-virilize him, giving him power over materials and labor. Computerized building descriptions are the written word that brings back to him the full power of the Vitruvian *auctoritas.*

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[106] And appealing to the mythical ideal of the Renaissance architect as a master builder. Gehry discusses these concepts in: Sheff, "Interview: Frank Gehry."

[107] This way the "organization of the artist" guarantees the architect's ultimate control over design and construction, preventing unwanted political, professional or business interests from compromising his artistic vision. For a longer discussion of Gehry's use of the term see: Bent Flyvbjerg, "Design by Deception: The Politics of Megaproject Approval," *Harvard Design Magazine*, no. 22 (2005): 50–59.

[108] Sheff, "Interview: Frank Gehry."

[109] Flyvbjerg, "Design by Deception."

[110] Evans writes about stone-cutting traits in the seventeenth century France as crucial artifacts for the establishment of the architect's social role and professional status. Evans, *The Projective Cast.*

Conclusions

In *Notes on the Underground*, Rosalind Williams discusses how the nineteenth century literary imagination construed subterranean environments —the mines, the tunnels— as a social (but also technological and ideological) underworld, intended for the "less ornamental aspects of society."[111] For academic architects, heirs to the nineteenth century *Beaux-Arts* imagination, the worlds of construction and labor are imagined, similarly, as architecture's social and technological underworlds. This chapter has reviewed the construction of this vertical distance through the accounts of historians and scholars of practice, identifying the successive devices —the written word, the drawing, the managerial control over trades— with which architects have established their professional authority, elevated themselves from the "drudgery" of labor, and claimed access to the spheres of power denied to artisans and workmen.

Architects in the United States had to struggle to define their own professional legitimacy. Without state patrons and in a competitive market, they had to negotiate a new professional identity from the conflict between the *Beaux-Arts* ideological construction of the architect as an artist, and the hierarchical reality of the workplace.

The tensions between US-American draftsmen and architects during the nineteenth and early 20th century, the evolution of the workplace towards larger corporate organizations, and the scientific managerial control over architectural practice[112] —accentuated by the successes of the war effort— shape the US-American architectural identity and set the stage where, at the end of the 1960s, computation crept into the frame of architecture.[113]

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[111] See Rosalind Williams, "Notes on the Underground, New Edition: An Essay on Technology, Society, and the Imagination" (April 30, 2008), http://mitpress.mit.edu/catalog/item/default.asp?tid=11420&ttype=2.

[112] Systematization precedes computation.

[113] With Ghirardo, Cuff, and Larson, I adopt the critical view that architecture is a culturally situated and *heteronomous* (as opposed to autonomous) practice that is better understood in relation to its cultural, social and professional contexts.

3. A TECHNOLOGICAL IMAGINATION OF DESIGN: THE *COMPUTER-AIDED DESIGN PROJECT* (1959-1967)

Introduction

Outline

During the post-war era, MIT engineers re-imagined design in the language of the machine. This chapter identifies and documents their "technological imagination of design," focusing on the discourses of design and design representation emerging around the culture of technology production developing around the *Computer-Aided Design Project,* a research operation funded by the US Air Force, active between 1959 and 1967, at MIT.

I will structure my analysis around three related threads. First I will show how, inspired by the dictates of the new science of cybernetics, the engineers in the project re-imagined design as the iterative performance of a problem-solving "man-machine" engine. Second, I will show how, by encoding centuries-old mathematical methods about perspective drawing in the computer, the engineers of the *Project* reconfigured design representation as the structured combination, in the computer, of Albertian perspectivalism and data processing. Third, I will examine the politics of representation, participation and authorship in their discourses about design. In particular, I will critically consider the tropes of neutrality and universality characterizing technology in design, arguing that they constitute the seminal discursive platform for contemporary design technologies and processes. I will show how, in these early discourses of design, technological systems are conceived of as "perfect slaves," becoming neutral vessels for design, and exerted influence beyond the boundaries of the project, having an immediate effect on the disciplines of architecture and urban studies at MIT.

To illustrate this, I will conclude the chapter by critically examining how the young Nicholas Negroponte, then a young researcher at the MIT School of Architecture and Planning, interpreted the *Project*'s theoretical and technological propositions to re-imagine architectural and planning practice. In my analysis, I critically consider the politics of representation, participation and authorship in his early works, and assess its efficacy as an architectural and cultural critique.[114]

MIT Context

During the post-war age MIT received more Federal funds for research than any other academic institution, and became the epicenter of a vibrant culture of research and development which derived in advances such as sensors, actuators, cathodic-ray tube monitors and computer graphics.[115] During this period, computers were still unique, expensive artifacts that only an academic and government elite could access. However, the notion of widespread personal computing was already part of the US-American popular imagination, fueled in part by the awe-inspiring wartime advances in electronics and by the contemporary promotion of technology and automation as patriotic endeavors.[116] Within this context of technological optimism, the *Computer-Aided Design Project* was funded through three consecutive contracts between the US Air Force and the Electronics Systems Laboratory and the Design and Graphics Division at the MIT Department of Mechanical Engineering[117] with the aim of improving design and manufacture of missiles, airplanes and their components for the US Air Force. The *Project*'s leader, Douglas T. Ross,[118] synthesized this objective in an internal report with a blunt "MORE AIRFORCE PER DOLLAR,"[119] providing a powerful illustration of the militaristic roots of the effort.[120]

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[114] I have published earlier versions of this chapter. See Daniel Cardoso Llach, "Inertia of an Automated Utopia: Design Commodities and Authorial Agency 40 Years After the Architecture Machine," *Thresholds*, no. 39 (July 2011): 39–44. Also, Daniel Cardoso Llach, "Esclavos Perfectos: Breve Historia De La Ciber-arquitectura En MIT (1959-1967)," *Dearq*, no. 10 (In press.). And Daniel Cardoso Llach, "The Invention of an Algorithmic Tectonics: Missiles, MIT, and the Computer-Aided Design Project.," *AD Architectural Design: Computation Works* (2012). (accepted for publication, 2012).

[115] Noble, *Forces of Production*.

[116] For an expanded discussion about the politics of technological discourse in post-war US, see Paul Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge: MIT Press, 1996) and David Noble, *Forces of Production* (New York: Oxford University Press, 1984). For an early mention to the "personal computer" see "Pocket Computer May Replace Shopping List", *The New York Times*, November 3, 1962.

[117] The first of the contracts began on December 1st, 1959, and the last one ended on May 3, 1967. The name "*Project*" was chosen to avoid being constrained by departmental boundaries (therefore speaking of the inter-disciplinary ambitions of the project)

[118] *Project* Engineer and Head of the Computer Applications Group in the Electronic Systems Laboratory.

[119] In capitals in the original. Douglas Taylor Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production: Interim Engineering Progress Report, December 1, 1963 - May 30, 1964*, M.I.T. Report ESL-IR 221 (Cambridge, Mass: Electronic Systems Laboratory, Massachusetts Institute of Technology, 1964), i.

[120] During the *Computer-Aided Design Project's* lifetime 12 technical reports were issued, several masters and doctoral theses, numerous memoranda and support documents explaining the technologies developed —which included programming languages, compilers, mathematical techniques for the geometric representation of free-form surfaces, hardware and graphics interfaces— for a total of 274 documents.

Outreach

Besides maximizing the military power of the US army through computation, a fundamental preoccupation of the project's leaders was to demonstrate the direct applicability of the technologies developed for the US industry. During the second contractual stage, the *Project* invited participants from the aircraft and weapons industries. The new contingent included programmers from Boeing, IBM, Lockheed-Georgia Company and the Grumman Aircraft Engineering Corp. The programmers moved to MIT via a transfer agreement between MIT and their employers in March of 1963. They were assigned to collaborate with the *Project*'s MIT researchers for one year. Their aim was to finish the "first phase" of research: the programming language and compiler AED-1, which would serve as the stem from which the first Computer-Aided Design system would "evolve." This —they hoped— would be the first step in the transference of knowledge from MIT into the industry. The importance of this transfer was stressed as a "bi-directional link" with "real-world" problems in the original invitation note sent to the companies:

> It is the firm objective of the Computer-Aided Design Project to provide a significantly new design technology which, following the successful traditions of the numerical control and APT System technologies, will be of direct benefit to the [US] American industry.[121]

The *Project*'s leaders hoped to promote interest among members of industry to develop more specialized Computer-Aided Design applications, and therefore connect the *Project*'s academic research with "real" problems. To accomplish this, the AED Cooperative Program was established in 1964.[122] It consisted of one-year fellowships intended to bring members of industry into MIT as a mechanism to promote the appreciation and diffusion of the technologies and ideas developed in the *Project.*[123] By fostering partnerships between academic research and companies, Air-Force sponsored programs like the *Computer-Aided Design Project* sought to plant seeds of innovation in the United States' industry.[124] In a 1965 report, the AED Program is described as "a successful blending of Air Force, industry, and academic interests."[125]

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[121] Ibid., 3

[122] AED stands for "Automated Engineering Design." See Douglas T. Ross, "The AED Approach to Generalized Computer-aided Design," in *Proceedings of the 1967 22nd National Conference*, ACM '67 (New York, NY, USA: ACM, 1967), 367–385, http://doi.acm.org/10.1145/800196.806006.

[123] Douglas Taylor Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production*, Report ESL-FR 351 (Cambridge, Mass: Electronic Systems Laboratory, Electrical Engineering Dept., Massachusetts Institute of Technology, 1968), 11, http://dspace.mit.edu/bitstream/handle/1721.1/755/FR-0351-19563962.*PDF*.txt;jsessionid=3469E7BE3780EDAF65F833757A012AF4?sequence=2..

[124] Some of the companies participating in the AED program included Boeing Co., Chevron Research Co., Dow Chemical Co., Ford Motor Company, Lockeed Martin, Grumman Aircraft (Coons's former employer before MIT), IBM Corporation. See D. T Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production: Combined Interim Engineering Progress Report, 1 June 1965 - 31 May 1966*, M.I.T. Report ESL-IR 278 (Cambridge, Mass: Electronic Systems Laboratory, Massachusetts Institute of Technology, 1966). p. 3. Today DARPA funds education

Project CAD and Project MAC[126]

Since 1963 the *Computer-Aided Design Project* was framed within a larger inter-departmental initiative called *Project MAC*, funded by ARPA (Advanced Research Projects Agency) through Office of Naval Research. MAC's goal was to "develop and foster man-machine problem-solving"[127] through time-shared computation, specifically by having a community of users connected to a computer through remote consoles, developing Interactive applications and problem-oriented programming languages. *Project MAC* emerged from the convergence of war-time efforts in graphic interfaces such as the SAGE,[128] the Electronic Systems Labs (which in 1950 had developed the first numerically controlled mill, operated with punched cards[129]) and the accumulated knowledge about time-shared[130] computing from the Timesharing project.[131] The *Project MAC* was planned around the IBM 7094 machine, a state of the art computer to which around 100 people on the MIT campus —including the researchers at the *Computer-Aided Design Project*— had access to it through remote ESL consoles. *Project MAC* was a cross-disciplinary research endeavor, crucial to the establishment of MIT as a world center of computer science. For the purposes of my analysis it is worth noting how the *Computer-Aided Design Project* preceded *Project MAC*, and is in fact one of its institutional origins. With Timesharing, Computer-Aided Design was at the root of MIT's history of post-war sponsored research that converged in *Project MAC,* resulting in the foundation of the MIT Laboratory of Computer Science in 1975,[132] the predecessor to MIT's quasi-legendary Course 6.[133] [See Figure 1]

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initiatives premised on "creative" hackers. See Mitch Altman et al., "DARPA Funding for Hackers, Hackerspaces, and Education: A Good Thing?" (presented at the HOPE Number Nine, The Hotel Pennsylvania, NYC, 2012). See also "The Pentagon Competes for Hacker Hearts and Minds » OWNI.eu, News, Augmented", n.d., http://owni.eu/2012/04/10/darpa-pentagon-hackers-us-maker-faire/.

[125] Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production*, 33.

[126] MAC stands for Mechanically Augmented Cognition or Multiple-Access Computer. Ibid., 3.

[127] Ibid., 2.

[128] The SAGE (Semi Automated Ground Environment) was the large-scale anti-aircraft defense system developed in the 1950s by the US Air Force with the crucial participation of MIT Jay Forrester's project Whirlwind at the Lincoln Labs. For an extended discussion of the SAGE system see Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (The MIT Press, 1997), 104.

[129] Douglas T. Ross was behind the development of APT, the first language for machine control.

[130] Time-shared machines allowed many users to connect remotely to a computer through consoles, living the access to its processing power. This was key in lowering the costs of computation. Time-shared computing was the dominant way of computing during the 1970s.

[131] Jack Belzer, Albert G. Holzman, and Allen Kent, *Encyclopedia of Computer Science and Technology: Pattern Recognition to Reliability of Computer Systems* (CRC Press, 1979), 341.

[132] In 1975 Project MAC is renamed as LCS (Laboratory of Computer Science).

[133] In MIT's idiosyncratic nomenclature system Course 6 is Computer Science.

Reconfiguring design: a Computer-Aided Design philosophy

Seeking a universal representation system: Ross and the *plex*

Despite their militaristic objectives, the engineers in the *CAD Project* followed what they thought was the most general approach to design possible. Rather than developing specialized applications or routines to solve particular "problems,"[134] (i.e. applications for the design of missiles, or aircraft) they sought to define a theory of design premised on the notions of design as man-machine problem-solving,[135] and of the computer as a universal representation machine. Their goal was to define a system general enough that it could be used to represent and compute elements of any field of application, such as "geometry, materials, aerodynamics, thermodynamics and *even* aesthetics"[136] in a language of discrete entities. In the following excerpt, the *Project's* leader Douglas T. Ross, nicely captures this aspiration of generality.

> From the Computer Applications point of view the primary problem is not how to solve the problems, but how to state them.[137]

A considerable effort was thus put into the definition of a general theory of abstraction intended to support the development of problem-oriented programming languages. An illustration of such theory of abstraction is the *plex*, a theoretical construct Ross defined as "an interweaved combination of parts in a structure... [with the purpose of representing a] thing, be it concrete or abstract, physical of conceptual."[138] In its more detailed definition, Ross describe the *plex* as the combination of three key components: *data*, *structure* and *algorithm*. The *data* are "units or indivisible entities in terms of which the 'thing's' properties are described or measured."[139] The *structure* refers to the relationships between the data, and the *algorithm* is "the capstone that allows the data in the structure to be interpreted, manipulated and filled with *meaning*."[140] The algorithm relates to the behavior and the interpretation of the whole: a

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[134] The engineers understood design as "problem-solving." Douglas Taylor Ross, *Computer-aided Design: a Statement of Objectives* (M.I.T. Electronic Systems Laboratory, 1960).

[135] "We have claimed that there is no distinction between computer-aided design and man-machine problem solving. Design is a special term for some ill-defined type of problem solving, but no special features are reflected in a system for design versus a system for general problem-solving." Ross, "The AED Approach to Generalized Computer-aided Design," 2.

[136] Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*, 8. (Italics are mine)

[137] Ibid., 191.

[138] Ibid., 14.

[139] Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*Douglas Taylor Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*

[140] Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.* (Emphasis added).Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*Douglas Taylor Ross, *Investigations in*

sort of logical rule set for operation and assembly. With the *plex*, Ross and the engineers behind the *Computer-Aided Design Project* sought to create a general theory of representation for describing (and computing solutions to) *any* problem. Whether the artifact to be designed was a servomechanism or a house, the *plex* was imagined as the multi-purpose representation instrument. To represent a line, for example, a *plex* entity had to be defined which contained sub-entities for its starting and ending points; each point sub-entity would in turn contain values for its *x* and *y* coordinates. Another sub-entity would describe the line itself, as an element with pointers to the other 2 sub-entities.[141]

Beyond representation, the modeling universe imagined with the *plex* provided also an interpretive apparatus (in the form of a processing algorithm) to transform the user's verbal or graphic representations into internal models with which the system could compute. The system was thus imagined as a self-consistent universe of interacting "meanings," with its own laws and logic, opaque to an external observer: a *black box*.[142] The following quote, from a paper entitled "Theoretical Foundations for the Computer-Aided Design System," illustrates these notions of self-containment and opacity.

> Since the entire process is based ultimately upon the interactions between the meanings of the many elements involved, and since the sorting out of what things go together is handled automatically by the "natural laws" of behavior which are built in, the designer on the outside has no conception of the chaotic activity inside the system, but sees only external effects appropriate to his mode of understanding.[143]

The *plex* illustrates the *Project*'s commitment to the development of a computational theory of abstraction premised on the notion of design as problem-solving. The engineers leading the *Project* sought to ground this theory by developing problem-oriented programming languages (such as the AED-0 and AED-1). Crucially for my analysis, the *plex* theory exposes a theoretical commitment by the *Computer-Aided Design Project* leaders to the idea that computational descriptions, because of their capacity to index "semantic" content, bear structural resemblances with the artifacts they are meant to depict.[144] In what

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*Computer-Aided Design for Numerically Controlled Production.*Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*

[141] The dissociation between data, structure and algorithm, explicit in the *plex*, is in a way essential for the programming of graphic representation systems. From this perspective, the *plex* theory suggests the imminent appearance of object-oriented programming. Sutherland's programming of the *Sketchpad* is often considered the first example of Object-Oriented Programming (OOP).

[142] In scientific fields, the expression "black box" refers to a system whose workings are opaque to an observer. In computation it's a common expression used to refer to aspects of a system that are beyond reach of a user.

[143] Douglas T. Ross and Jorge E. Rodriguez, "Theoretical Foundations for the Computer-aided Design System," in *Proceedings of the May 21-23, 1963, Spring Joint Computer Conference*, AFIPS '63 (Spring) (New York, NY, USA: ACM, 1963), 318, http://doi.acm.org/10.1145/1461551.1461589.

[144] One of the tenets of this assumption (related to fabrication technologies) is the idea of symbolic manipulation and representation as *plans* preceding and prescribing material action.

follows, I discuss how the encoding of perspective geometry in the computer enabled the *Project's* engineers to widen their claims about the structuredness of digital representations and about the universality of the computer as a representation machine, effectively configuring a new kind of epistemological link between representation and object. [Figure 2]

Reconfiguring design representation: Roberts and the perspective hack

During the fifteenth century, architects like Filippo Brunelleschi and Gian Battesti Alberti helped establish the graphical methods of perspective drawing that enabled artists and architects to represent three-dimensional space in the two-dimensional space of the plane with perceptual accuracy. In the early days of the computer age, MIT engineers had to re-discover these mathematical methods in order to build them into the new language of the computer.

Larry Roberts,[145] who as a Masters and Ph.D. student in electrical engineering worked on the TX-0 and TX-2 computers at MIT during the early 1960s,[146] was the first to create a computer program able to display a three-dimensional object in perspective, from different angles. To accomplish this, he translated the graphical and mathematical methods of perspective into the binary language of the computer.[147] For his doctoral thesis, Robert's worked on a computer program that could interpret a 3-D shape from a photograph of a planar solid.[148] To accomplish this, Roberts pioneered some of the first "computer vision" methods for parsing a digital reconstruction of a solid's photograph, but faced the challenge of generating a description of the 3-D element from any given point. Unable to find a precedent, Roberts "hacked" a solution by studying and combining two separate bodies of literature: mathematical methods for perspective geometry, from German textbooks from the 1800s, and the (more conventional) knowledge about matrices.[149]

> It turned out there was no technology in the U.S. or in the world at that point in time integrating both matrices and perspective geometry. Somehow the two had been totally separated in time and space throughout the world. So I went back to the German textbooks and found out how perspective geometry was done

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[145] Roberts had a leading role in developing the ARPANET, an early predecessor to the Internet. His most famous contribution was the idea of packet switching, a technology for data transmission fundamental to computer networks.

[146] Roberts recalls he logged more than 600 hours in the TX-0 machine, an "astronomical amount of time to be able to spend personally on one of those machines in that era." *SIGGRAPH '89: ACM SIGGRAPH 89 Panel Proceedings* (New York, NY, USA: ACM, 1989), 56.

[147] Roberts is responsible for developing the first algorithm for eliminating the lines of the hidden faces of a 3-D object.. At 29 Roberts was appointed as Arpanet's architect, and was key in the world's first computer network.

[148] This was the subject of his thesis: Lawrence G. Roberts and Peter Elias, "Machine perception of three-dimensional solids" (Ph.D., Massachusetts Institute of Technology, 1963).

[149] Ibid.

> and that [these books] had no knowledge of matrices, of course, and put the two together and created the four-dimensional homogeneous coordinate transform, which is widely used today for perspective transformations.[150]

The result of this hack was the four-dimensional transform with which Roberts was able to encode[151] the homogeneous coordinates of perspective geometry in matrix form. The method allowed him to visualize a 3-D object from any given "camera" point, on the computer screen. Roberts recalls his work during this time in a modest and somehow playful way.

> The homogeneous coordinates in matrix form was [sic] my invention. The concept, the word homogeneous came from the 1800s, in terms of their handling of perspective geometry, but again it was all in terms of individual equations and not in matrix. So throughout this whole period we were picking up old things that people had done… and applying it to the real world… We were picking up math and applying it, and it was certainly new in the computer field but it wasn't new in perspective geometry.[152]

By "hacking into" perspective mathematics from the 1800s German textbooks, and putting it in terms of matrix operations, Roberts encoded the Renaissance perspectival vision in the computer. His contribution establishes the foundations of the distinctive representational tradition of our age: a hybrid of Albertian perspectivalism and data processing.[153] The emergence of this tradition gave support to technologists' aspirations about the universality of the computer as a representation machine. This reconfigured notion of representation led the engineers in *The Project* to re-imagine different forms of design practice, endowing them with a new sense of materiality and structure [See Figures 3 and 4].

The *Project's* engineers imagined computerized descriptions as fundamentally distinct from paper drawings. Unlike paper drawings, computerized descriptions were structured combinations of different kinds of *data*, making it possible for a geometric representation to index information about non-geometric aspects of a design. In this they saw a distinct quality, and an opportunity to re-imagine design practices.

In a paper entitled "Outline of the Requirements for a Computer-Aided Design System"[154] Steven A. Coons —a professor of Mechanical Engineering and leader, with Ross, of the *CAD Project*[155]— writes that

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[150] *SIGGRAPH '89.*

[151] Roberts's move was permitted by the fact that perspective geometry was already a structured, mathematized form of reprsentation, prior to its mechanization and automation via computation. The word "encoding" evokes the processing of data through computer code, but also the "codification" of practice observed by Giedion to precede mechanization. Siegfried Giedion, *Mechanization Takes Command: A Contribution to Anonymous History* (W. W. Norton & Company, 1969).

[152] *SIGGRAPH '89.*

[153] Roberts claims to have coined the phrase "computational geometry" in 1970.

[154] Steven Anson Coons, *An Outline of the Requirements for a Computer-Aided Design System*, M.I.T. Electronic Systems Laboratory. Technical Memorandum ESL-TM-169 (Cambridge: M.I.T. Electronic Systems Laboratory, 1963).

"in the design process the designer is concerned with a large set of variables," some of which he describes as "continuous, like the weight of a certain part," and some as "discrete 'point sets' (like material: steel, brass, lead, plastic)." Coons saw that abstract representations in the computer could be used to create associations between the variables, which could be "interrelated, or cross-coupled, in a very complex way."[156] Coons thus transforms the designer's engagement with the representation and the epistemological link between representation and object.[157]

Coons's student, Ivan Sutherland,[158] gives insight into these reconfigurations. He saw the production of computerized descriptions as "an entirely different activity" from traditional drafting, more akin to programming than to hand drawing because of the structured nature of computer code.[159] In Sutherland's telling description of drafting, pencils or ink on paper are only capable of making "dirty marks on paper:"[160]

> An ordinary draftsman is unconcerned with the structure of his drawing material. Pen and ink or pencil and paper have no inherent structure. They only make dirty marks on paper. The draftsman is concerned principally with the drawings as a representation of the evolving design.[161]

Sutherland's "ordinary draftsman" is solely concerned with the correspondence, or resemblance, of the drawing with the physical artifact it describes; this correspondence is posited as a disadvantage.[162] But

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[155] He was also the director of the Design and Graphics division in the Mechanical Engineering Department at MIT.

[156] Coons, *An Outline of the Requirements for a Computer-Aided Design System.*

[157] It's worth noticing that Coons was an expert in graphic representation, and co-authored an extensive manual of engineering graphic standards and draftsmanship. John T Rule, *Graphics* (New York: McGraw-Hill, 1961).

[158] As a graduate student in Electrical Engineering at MIT, under Professor Coons's supervision, Ivan Sutherland developed the first interactive computer graphics system, the Sketchpad, in 1963. The Sketchpad is conventionally considered as the first interactive graphic system, and thus the origin of Computer graphics and CAD.

[159] As context, Ina Wagner and Hilda Tellioglu provide a useful discussion of the distinctive forms of work involved in software development, where a great amount of effort goes into defining infrastructures for collaboration, common interfaces, and modules that comprise the software's architecture. In their study, a team of programmers in a particular project would devote time to specify coding styles and "on making sure the structure of the program as well as the composition of each module was understood by all." Technological compatibility is also a primary concern. The cost for a system to pay no attention to these concerns would be to be left out of a global market of software goods." This is the ethos thinkers like Sutherland imagined for the production of design descriptions. Hilda Tellioğlu and Ina Wagner, "Software Cultures," *Commun. ACM* 42, no. 12 (December 1999): 71–77.

[160] Ivan Sutherland, "Structure in Drawing and the Hidden-Surface Problem," in *Reflections on Computer Aids to Design and Architecture*, ed. Nicholas Negroponte (New York, 1975), 73–77 (excerpt not including the "hidden surface problem."

[161] Ibid.

[162] Sutherland's description of a draftsman unconcerned with the structure of the drawing may not be an entirely accurate observation. Histories of draftsmanship represent a different reality, of an extremely structured and regimented practice (See Chapter 2, in particular the review of Johnston, *Drafting Culture.*). On the other hand, perspective drawing was *already* a mathematized form of spatial description. For an illustration of this, see Latour's discussion of Booker's observation that linear perspective progressively "changed the concept of pictures from being just representation to that of being projections onto planes." See Bruno Latour, "Visualisation and Cognition:

what concerns us here is that Sutherland posits the newly found structured character of computer-generated descriptions to be an argument for a topological resemblance —already present in the *plex* theory— between the act of producing a computational drawing and a physical artifact. This led him to posit that creating descriptions with a computer was the work of an engineer, not a draftsman. Sutherland believed that the crucial challenge for the new emerging culture of computational design was to not think of computer-generated graphics as "drawings of a design," but instead as a computerized descriptions that are *built* instead of *drawn*: essential to this view was the idea that computer-generated descriptions of buildings are not "drawings," but a sort of "constructs" with a materiality and structure of their own —a new kind of representational artifact with the potential to enable a designer to link different kinds of information, with geometry, to describe a building.[163]

> As soon as the process of computer-aided design is considered as building a computerized description of the object being designed, rather than as the process of drawing the object being designed, horizons become tremendously expanded. In the architectural world, for example, one should think of computer-aided design as producing not only graphical outputs but also material lists; labor estimates; floor area computations; heating, lighting, and ventilation simulations (to demonstrate de adequacy of the design); as well as many other auxiliary outputs. Only when the computerized version of the design is the master document from which all auxiliary information is derived, preferably with computer assistance, will a complete computer-aided design system have been created.[164]

Sutherland was also aware of the re-organization of work the new form of representation suggested [See Figure 5]. Before networked computing was the dominant paradigm of computation, he contended that a "computer-design system can provide a communications mechanism between a multitude of users and thus reduce the cost of design jobs that are too big for one person"[165] thus anticipating a key *Building Information Modeling* theme. Morover, Sutherland's theory of difference between the engineer and the draftsman shows how the reconfiguration of practice latent in their discourses had a disciplinary dimension: machines and software are imagined as constitutive of boundaries between professional groups.

The engineers' construction of design representations as forms of *building* outlined a way of thinking about design as a structured process of information management, and enabled them to speculate about

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Drawing Things Together," in *Knowlegde and Society: Studies in the Sociology of Culture Past and Present*, vol. 6 (Jai Press, n.d.), 25.

[163] This ideas resonate with present-day definitions of Building Information Modeling and "concurrent design. See, for instance, Witt, "Concurrent Design."

[164] Sutherland, "Structure in Drawing and the Hidden-Surface Problem," 76.

[165] Ibid.

new forms of division of labor. In what follows I discuss how ideas about work are reconfigured in the *Project's* discourses of design.

Reconfiguring work: Steven Coons's Perfect Slaves

Besides the development of programming languages and abstract structures like the *plex*, the *Project*'s leaders also saw in computers an opportunity to theorize new forms of division of labor in design. Inspired in the discourses of cybernetics[166] that construed human-machine interaction as a symbiosis between two organisms, the *Project*'s engineers re-imagined the designer's role in relation to what were perceived as the machine's capacities. In their cybernetic theory of design, the *Project* engineers assigned complementary roles to each part of the human-machine assemblage, defining the boundaries of what constitutes creativity and work.[167]

During his participation in the *Project* as leader of the Design and Graphics team, Coons made crucial theoretical and technical contributions to the emerging fields of Computer-Aided Design and Computer Graphics [See Figure 6]. He was also an ardent promoter of computational design and manufacture methods across fields.[168] One of his crucial contributions was the development of mathematical techniques for describing three-dimensional curved surfaces (he called them "patches"), first by the definition of methods for the non-parametric interpolation of a patch between four edge curves, and then through the definition of parametric methods based on a set of polynomials.[169] As a professor of mechanical engineering, Coons led crucial developments in computer graphics and computer aided manufacturing. For instance, he oversaw the first interactive computer graphics display, the *Sketchpad*, developed by his student, Ivan Sutherland, under his supervision.[170]

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[166] A particularly influential paper for members of the *Project* was: J.C.R. Licklider, "Man-Computer Symbiosis", 1960, http://groups.csail.mit.edu/medg/people/psz/Licklider.html. Cybernetics was then a new scientific field seeking to use the formalisms and analytical framework of Shannon's *Information Theory* for the representation and control of (biological, mathematical, social, mechanical) systems as flows of messages, and feedback loops. The influential Information Theory was first formulated for telephonic communications in: Claude E Shannon and Warren Weaver, *The Mathematical Theory of Communication* (University of Illinois Press, 1998). Cybernetics was formulated by Norbert Wiener in Norbert Wiener, *Cybernetics, Second Edition: Or the Control and Communication in the Animal and the Machine*, second ed. (The MIT Press, 1965).

[167] Ross, the *Project*'s leader, explains: "The synergetic integration of the creative abilities of the human with the immense capacity of hardware and software in the computer, in a man-machine problem-solving team Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production.*

[168] Coons was an enthusiastic advocate for the use of computers in art, architecture and design. See, for instance, Coons, "Computer, Art & Architecture."

[169] These methods are, still today, the foundation of commercial software surface representation algorithms.

[170] See "Sketchpad: A man-machine graphical communication system" (Ph.D. Diss., Massachusetts Institute of Technology, 1963).

Crucially for my analysis, Coons conceived design as an iterative process of representation and analysis where a "creative stage", in which a design representation is created, is followed by a "mechanical stage," in which the representation is tested against different metrics such as mechanical stress and overall structural performance. Coons believed that the "creative stage" was better suited for human designers while the "mechanical stage" could be successfully automated.[171] This view was one of the theories guiding the *Project*'s technical efforts. In an Electronic Systems Laboratory technical memorandum from 1963, entitled "Requirements for a Computer-Aided Design System," Coons imagines CAD in cybernetic language as a system joining "man and machine" in an "intimate cooperative complex, a combination that would use the creative and imaginative powers of the man and the analytical and computational powers of the machine each with the greatest possible economy and efficiency."[172]

The human-machine relationship formulated in this statement—and adopted by the *Project* at large— evoked the cybernetic idea of symbiotic assemblages of machine and human as a single organism. Through the cybernetic lens, Coons and the *Computer-Aided Design Project* envisioned design as an iterative process of machine-enhanced representation and analysis, and machine-driven manufacture:

> The different powers of man and machine are complementary powers, cross-fertilizing powers, mutually re-enforcing powers. It is becoming increasingly clear that the combined intellectual potential of man and machine is greater than the sum of its parts.[173]

Coons's characterization of human-machine difference suggests a clear power hierarchy where computers are slaves with humans as their masters. Design is thus imagined as a cybernetic feedback loop between representation, analysis and materialization, where a "creative moment" —during which a design representation is created— is followed by a "mechanical moment" —during which the representations are evaluated in the light of different metrics— such as resistance to tension, compression, and overall structural performance. Crucially, Coons[174] believed that the "creative moment" was better suited for the human designers, while the "mechanical moment," consisting of analytical, material and numerical aspects, could be successfully automated.

> We envisioned even then the designer seated at a console, drawing a sketch of his proposed device on the screen of an oscilloscope tube with a "light pen,"

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[171] About the testing stage Coons wrote: "These are all essentially mechanical operations, however, and it is quite clear that at least in principle, the computer can be made to deal with all of them." Steven A. Coons, "An Outline of the Requirements for a Computer-Aided Design System," In *Spring Joint Computer Conference, Detroit, Michigan* (New York: ACM, 1963), 301.

[172] Coons, *An Outline of the Requirements for a Computer-Aided Design System*, 300.

[173] Ibid.

[174] And his colleagues at the *Computer-Aided Design Project.*

> modifying his sketch at will, and commanding the computer slave to refine the sketch into a perfect drawing, to perform various numerical analyses having to do with structural strength, clearances of adjacent parts, and other analyses as well.[175]

Coons's imagination of design illustrates the influence of cybernetic discourses in the *Project*'s theories about Computer-Aided Design. Moreover, it reveals how the conceptions of creativity, design, and work, are established, re-organized and re-configured, in the *Project's* discourses, in relation to their place in a technological framework. From this point on, an epistemological shift occurs: technology can no longer be understood as a *tool* for design, but as its *infrastructure.*[176] I will now consider how one of Steven A. Coons's students, the then young architect Nicholas Negroponte, adopted the *Project's* technical and theoretical idioms to re-imagine architecture and planning.

The architect and the machine: Nicholas Negroponte and the Computer-Aided Design Project[177]

"Perfect slaves" and "mechanical partners"

Today, Nicholas Negroponte is mostly known for his work as chairman of the *One Laptop Per Child* (OLPC) foundation, a global non-profit endeavor seeking to provide poor children with small laptops, promoting computers as crucial vehicles for individual and collective self-education. However, the fact that Negroponte's techno-cultural entrepreneurship originated in the arena of *Computer-Aided Design* is far less known.

In the spring of 1966, when the *Computer-Aided Design Project* was in its most intense phase of development, Negroponte —then a Masters of Architecture student at MIT— attended Steven A. Coons's course "Computer-Aided Design." In his notes, Negroponte described the class as a "study of man-machine synthesis via graphical intercourse."[178] The class was structured around Coons's own method[179] for describing and manipulating three-dimensional geometric elements in the computer,[180] and

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[175] Ibid.

[176] This theme is developed in more detail in chapters 6 and 7 in regards to the Building Information Modeling project.

[177] This section draws from my earlier article Cardoso Llach, "Inertia of an Automated Utopia: Design Commodities and Authorial Agency 40 Years After the Architecture Machine."

[178] Nicholas Peter Negroponte, "The Computer Simulation of Perception During Motion in the Urban Environment." (Massachusetts Institute of Technology, 1966), 99, http://dspace.mit.edu.libproxy.mit.edu/handle/1721.1/13288.

[179] Succinctly known the "Coons method."

[180] Negroponte, "The Computer Simulation of Perception During Motion in the Urban Environment."

the matrix transformations for perspective projection first developed by Roberts. The course was influential to Negroponte, who became one of Coons's advisees, and wrote a thesis where he contended that computers could be thought of as machines for "simulating perception."[181] After graduating, Negroponte sought to expand the influence of the advancements in computer research by the *CAD Project* into the fields of architecture and urban planning —now as a young professor and researcher at the MIT School of Architecture and Planning, through his research lab "Architecture Machine" [See Figure 8].

In this section, I focus my analysis on the collection of research projects and theoretical propositions in Negroponte's 1970 book *The Architecture Machine*, placing it within the theoretical and technological framework developed by the *Computer-Aided Design Project*, illustrating the *Project's* reach beyond the departmental and disciplinary boundaries. While an array of fields celebrates *The Architecture Machine's* pioneering enunciation of key human-machine interaction paradigms, including gestural and windows-based interfaces, I'd like to situate it in the intellectual context of technology production at MIT, interrogating its ambition to use technology as a vehicle of social —and architectural— critique. In particular, I critically approach *The Architecture Machine's* socio-technical utopia where architectural practice is imagined as a playful, democratizing conversation between humans and machines.[182]

Human-Machine Encounters: "Ted, many conflicts are occurring"

> Let us build machines that can learn, can grope, and can fumble, machines that will be architectural partners, architecture machines.[183]

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[181] Ibid.

[182] Negroponte and the other proponents of *The Architecture Machine* at MIT were not alone in their pursuit. Information theory and computers played an important role in the imagination of architects at the time. Among those ideologically close to Negroponte and the Architecture Machine Group was Hungarian-born French architect Yona Friedman. Negroponte met Friedman in 1964 while still a graduate student when he was asked to serve as Friedman's interpreter in the US. They eventually became collaborators and, in his foreword for Friedman's book, Negroponte acknowledged the commonalities between their projects. The theme of a technologically enabled participatory architecture was at the center of Friedman's *Towards a Scientific Architecture*, a speculative piece that advocated a "direct feedback" between the user and an architectural "expert system" for the production of designs. In his book, Friedman pejoratively labeled the architect as an elitist "middleman" to be bypassed in order to liberate the dweller (branded here as "user") from the assumptions of the professional designer. Like Negroponte, Friedman used information-theoretical idioms for articulating what he conceived of as a more "scientific" design process. Friedman states, for instance, "epistemology is essentially information theory in disguise." See Yona Friedman, *Toward a Scientific Architecture*, trans. Cynthia Lang (The MIT Press, 1980), 6. For a very rich source of reference on the influence of cybernetics and information theory in architectural discourse in Great Britain during the 1960's see Upitis, "Nature Normative." The observation of Negroponte and Friedman's ideological commonalities can be found in Robert Bruegmann, "The Pencil and the Electronic Sketchpad: Architectural Representation and the Computer," in *Architecture and Its Image*, ed. Eve Blau and Ned Kaufman, Catalog of Inaugural Show at Canadian Center for Architecture (Montreal, 1989).

[183] Nicholas Negroponte, *The Architecture Machine: Toward a More Human Environment* (The MIT Press, 1973), 121.

Instead of presenting a single artifact, as its title suggests, *The Architecture Machine* introduces a collection of different scenarios and experiments. Throughout the book, two main themes are developed. The first explores computers are thought of as artificial experts guiding the dweller through design choices until a unique and optimal residential solution is reached —a sort of architectural version of an "expert system."[184] The second posits a computer network as a communication platform between a community and a human designer. Under this premise, the network's central processor interprets the community's preferences into clear spatial guidelines to be followed by a human architect, thus penetrating "the designer-dweller dissonance that exists in today's housing problem."[185] Both themes position technology as a vehicle to bypass architects and planners, professionals Negroponte saw as elitist middlemen standing between the "people" and good design.[186]

As a proof of concept for the first (the "expert system") category, Negroponte presents URBAN5, a computer-aided design system comprising a cathode-ray tube monitor, a keyboard, an optic pen, and a small console with several controls —including a "PANIC" button. The system receives text commands from the user as inputs and interprets them as geometric and spatial constraints, calculates a response to the inputs, and displays it on the cathode-ray tube monitor as compositions of three-dimensional cubes.[187] If the program cannot adequately match the input to a response it requests further specification from the user; in case of conflicting constraints, URBAN5 displays gentle alerts on the screen. The stated aim of URBAN5 is to test the desirability of natural language as a communication medium between humans and machines [See Figures 9 and 10].[188] However, URBAN5 did not fulfill their makers' expectations because of its inability to enact what they thought were the attributes of a truly adaptable architecture machine:

> Playing is learning, but URBAN5 has not been sufficiently sophisticated actually to frolic; instead it has inexhaustibly printed garbage [...] URBAN5

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[184] Expert systems are a type of computer program that is supposed to perform a human expert's task. Such systems are founded on the notion of "knowledge capture:" the idea that a "knowledge engineer" can study and encode in a computer program the decision-making process and expertise of a human subject. For a sharp perspective on the culture of "knowledge engineering" and artificial intelligence see Diana Forsythe and David J. Hess, *Studying Those Who Study Us: an anthropologist in the world of artificial intelligence* (Stanford: Stanford University Press, 2001).

[185] Negroponte, *The Architecture Machine*, 55.

[186] This is consistent with the *Computer-Aided Design Project's* view of "design bureaucracy." See caption to Figure.

[187] Today we would call these cubes "voxels", a word that wasn't available at the time *The Architecture Machine* was written.

[188] The form of human-machine interaction proposed in URBAN5 echoes contemporary experiments in language processing, specifically the early language processing program *Eliza* developed in 1966 at MIT. Eliza is a computer program that uses a simple "pattern-matching" algorithm to assign pre-canned phrases as responses to sentences entered as text by the user. The interaction with the program gave the user the impression—generally for a brief time—of having a conversation with a human (the program simulates being a Rogerian psychotherapist). Eliza was written in 1966 by Joseph Weizenbaum at MIT, and is considered an early example of automated language processing. There are many available online implementations of the program. One can be found at "Eliza Test", accessed January 10, 2011, http://chayden.net/eliza/Eliza.html.

> suggests true dialogue, suggests an evolutionary system, suggests an intelligent system —but, in itself, is none of these.[189]

An example of the second, "participatory" category is the "*Hessdorfer Experiment*," in which three African-US-American men from "Boston's ghetto area" are asked to interact with a machine — comprising only a keyboard and a printer head remotely operated by one of the researchers— that interrogates them about their "urban needs." In the book, Negroponte celebrates that during the experiment the subjects (who thought they were communicating with an autonomous machine) "did not type uncalled-for remarks," arguing that the men engaged the machine in a way that wouldn't have taken place if the interlocutor was a "white planner or politician."[190] The book thus presents the experiment as evidence of the computer's potential to foster a more transparent conversation with members of a "community." The fact that the book is outdated from a racial, nomenclatural point of view, is self-evident, but the kind of neutrality Negroponte is willing to attribute to the machine is worthy of notice. In the *Hessdorfer Experiment*, the machine is assumed as a neutral device that helps the researchers conceal their personas and, quite specifically, their *whiteness*.[191] [See Figure 11]

David Noble wrote, "technology rarely fulfills the fantasies of their creators. As people are fallible, so too are their machines, however perfect, complete, and automatic the designs."[192] Yet, even failed technologies carry a blueprint of its makers' time, desires, and questions. URBAN5 and the machine in the *Hessdorfer Experiment* project design as a collaborative, quantifiable and evolving dialogue with always-adapting machines, expressing a desire for design to become a more rational and "social" endeavor — devoid of what Negroponte construes as the elitist subjectivity of the human architect. *The Architecture Machine's* aspirations to dilute the designer's authorial agency through mechanically-enabled participation expresses an anxiety about the social role played by the disciplines of architecture and planning. In Negroponte. The aspiration is phrased in a populist language, that seeks to give people, through technology, the *right* to design their own environments.[193]

Rephrasing machines as social agents

Aside from a post-structural fantasy of "killing the author," the symbolic demotion, or reconfiguration, of the architect in *The Architecture Machine* should be understood as a rationalist reaction to the

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[189] Negroponte, *The Architecture Machine*, 93.
[190] Negroponte, The Architecture Machine, 50.
[191] While also concealing the politics of the experimental set up.
[192] Noble, Forces of Production, 325.
[193] A few years later, in a less enthusiastic tone, Negroponte would admit the naïveté of these experiments (see Nicholas Negroponte, Reflections on Computer Aids to Design and Architecture (New York: Petrocelli/Charter, 1975)) the notion of democratic empowerment through technology remained a constant of his work nonetheless.

individualistic notion of author as a sole creator inherited by architecture from L'Ecole de *Beaux-Arts* —in fact, Bruegmann places Negroponte in a tradition of rationalism that goes back to J.N.L. Durand.[194] The notion of a machine that learns by itself is instrumental in affording Negroponte the space to ignore questions about the machine's nature as a designed artifact, and to inspire questions about authorial agency in computer aided design:

> When a designer supplies a machine with step-by-step instructions for solving a specific problem, the resulting solution is unquestionably attributed to the designer's ingenuity and labors (...) Whenever a mechanism is equipped with a processor capable of finding a method "of finding a method of solution," the authorship of the answer probably belongs to the machine.[195]

The rhetoric of participation and democracy discussed above shows how *The Architecture Machine* seeks a larger cultural goal besides architectural critique. Primordially, to challenge cultural critics who, like Mumford, were concerned with the de-humanizing aspects of a technological society, and with the rise of an unquestionable scientific ideology. As a reaction, *The Architecture Machine* represents computers —and CAD— as agents of social and environmental democratic activism. Crucial to the advancement of this vision is a rhetoric that speaks of machines as social entities mirroring the attributes of humans, while directing attention away from the technologist's role as the machine's designer. This point deserves careful analysis.

In *The Architecture Machine* Negroponte adopts the technologies developed by the *Computer Aided Design Project* as the constitutive elements of his vision. However, he rejects the dualism between creativity and analysis that rendered computers as the "perfect-slaves" of a design process.[196] Instead, Negroponte deploys a language endowing computers with human-like attributes such as curiosity and judgment, construing human-machine interaction as the "cohabitation of two intelligent species,"[197] as a symbiotic relationship that gave origin to an "extended designer", and as an "ecology of mutual design complementation, augmentations, and substitution."[198]

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[194] Bruegmann, "The Pencil and the Electronic Sketchpad", 140.

[195] The repetition is in the original, speaking of the desire of generality. Instead of seeking a solution, what is sought is a method for finding *any* solution. Negroponte, *The Architecture Machine*, 11

[196] In a 1966 lecture Coons described computers and numerically controlled manufacturing technology as "perfect slaves" who would take over the most laborious and repetitive aspects of artistic and engineering production—a statement that notoriously resembled Alberti's ideas about the distinction between the architect (who draws) and the "skilled craftsman" (who makes). I discuss this iin more detial in Cardoso Llach, "Design and the Automated Utopia: Certain Assumptions in Digital Design Culture."

[197] See Negroponte, *The Architecture Machine*, 7 & 17.

[198] Despite these rhetorical differences, Coons's themes are audible throughout *The Architecture Machine*. Among these, the notion of adaptability deserves special analysis. Coons distinguished between two different CAD philosophies, one that relied on a large set of specialized procedures and another that relied on a single one that *adapts* to its context. Coons was wary about the risk of narrowing the space of design alternatives in a computer-aided design

By re-positioning machines as humans, *The Architecture Machine* seeks to overcome —rhetorically at least— the mechanical-organicist polarity that concerned those who saw technology and people in opposing camps.[199] But the move to equate humans and machines reproduced the polarity because, by using a symmetric language that obscured the machine's complex ties to its makers, it broke the bridge between the two. From a "perfect-slave," by virtue of *The Architecture Machine,* technology came to be represented as human. Both views, however, shut down technology's material and cultural specificity as domains of analysis. For this reason *The Architecture Machine* fails both as an architectural and social critique.

Considering, with Lewis Mumford, technologies as embodiments of social relations, and *The Architecture Machine*'s still-abundant progeny in academic research and industry circles,[200] we can think of the socio-

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system by overloading the software—and the user—with a large set of very specialized procedures. See Coons, "An Outline of the Requirements for a Computer-Aided Design System," 301. In *The Architecture Machine* Negroponte echoes the contrast between these two philosophies by opposing the notion of flexibility —the capacity of a system to be extended within a fixed set of constraints— to the notion of adaptability —the ability of a single computational procedure to find solutions to different problems. In Coons's and Negroponte's view, user interfaces and programming languages could provide flexibility, but not "true" adaptability:
"We have a condition in where each designer is creating his own library of services out of the problem-oriented [programming] language. Once created, note that these operations are no less rigid than the predefined package of design commodities." Negroponte, *The Architecture Machine,* 27. However, the means and methods to achieve adaptability are never discussed, and thus adaptability remains as a suggestive device —a black box enclosing computers' hoped-for potential to revert the perverse effects of industrial standardization and of the notion of l'homme type on architectural and urban space. The notion of *l'homme type* (French for "man-type", or "typical man") was a collection of anthropometric assumptions about architecture's "end-user" advanced by advocates of modern architecture, especially in the first half of the twentieth century, to facilitate (and legitimize) standardized residential housing design. Abiding by these assumptions could only yield, in Negroponte's view, impersonal and banal architecture.

[199] "What needs to be articulated, regardless of the format of the man-machine relationship, is the goal of humanism through machines. (...) The concern is to avoid dehumanizing a process whose aim is definitely humanization." See Negroponte, *The Architecture Machine,* 7. Matthew Wisniosky's history of engineers' temporary reconciliation with social theory during the fifties and sixties captures and elaborates on the contrast between these two postures about technology and society by distinguishing between two philosophies, a *theory of technological change,* which attributes agency to technology as a semi-autonomous force, and a *theory of technological politics,* which considers technology as an "embodiment of social relations." Matthew Wisniosky "Engineers and the Intellectual Crisis of Technology" (Ph.D. diss., Princeton University, 2005), 6.

[200] Some futures never get old. Despite some superficial differences, the ambition (illustrated in Negroponte's work) to enable an objective and scientific approach to design by replacing a human architect with a machine, is alive and well in contemporary design cultures. The languages of today's *Architecture Machines* have shifted from the mechanistic idioms of robotic experts, into a blend of biological and computational metaphors. The new idioms reflect the dominance of a new techno-scientific (and eco-moral) paradigm, but the rationalist drive remains intact under the new rubric of the "performance-based." In today's *Architecture Machines,* the emphasis on the idea of adaptability is no longer deployed through the fantasy of an artificial mind, but through biologically inspired, computationally obtained variation. The reaction against the architect's subjectivity is not enacted by human-like machines, such as those advanced in Negroponte's vision, but by the unquestionable, faceless authority of an algorithmic conception of the natural. Tropes of democracy and participation in design persist in the desire of diluting authorial agency in the assumed pluralism of multi-user Internet applications. On the hardware side, the electronic sketchpads of cathode-ray tube monitors are replaced today by hopeful interpretations of associative software platforms, plasma screens and increasingly precise layer deposition 3-D printing technologies.

technical utopia of empowerment via adaptable, social, democratic —and "neutral"— machines, as inaugurating MIT's own particular sort of technocratic idealism.[201]

The Negroponte paradox: Prescribing participation

The imaginaries of participation set in motion by *The Architecture Machine* —the vision of a technologically democratized planning and design— anticipate a global cultural enterprise of construing technology as a democratizing force, uplifting supposedly under-privileged, *non-white* and "third-world" communities. The vaguely described "third-world" child subjects who constitute the targets of the OLPC project are the contemporary equivalents of the carefully chosen black African-American Boston residents in the "Hessdorfer experiment." In both cases, unmanned technological systems —for education and design, respectively— are presented as platforms of *bottom-up* development. What remains obscured by assuming, like Negroponte does, the neutrality of such systems, is the fact that setting up the technological stages for the imagined bottom-up processes constitutes a *top-down* operation[202].

Paradoxically, the emancipatory discourse of technologically-enabled participation frames the tacit claim that, without technology, subjects are ill-suited to *participate*, and thus are devoid —in discourse— of political and social agency. Participation is, in this sense, a colonizing trope[203] that seeks to shape the subjects into prescribed modes of agency construed as the only valid forms of political and social action.

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[201] Negroponte's techno-cultural entrepreneurship in *The Architecture Machine,* is framed as a critique of the "gentleman architect," an idea of architectural practice predicated on the notion of the inherent value of dwellings and urban spaces by virtue of their uniqueness. By proposing to automate the production of uniqueness —via machines that amortize the time and labor involved— Negroponte's work anticipates a desire —and a market— for digitally mass-customized goods. In short, it shaped the *act* of design into a valuable commodity, defining it in turn as the symbolic, bounded, manipulation of abstract objects. While it would be unproductive to attempt to quantify the success or failure of the compelling technological utopia registered in *The Architecture Machine* in terms of its social "impact," given the distance between its ambitions of social change, and the ironies of its deployment into popular culture, it may be worth noting that Negroponte's inversion of the design equation —from the gentleman *architect* into the gentleman *dweller*— does not fundamentally alter the nature of the transaction.

[202] In the case of the OLPC project, the "top-down" approach is literal, as Negroponte intended to throw the computers from helicopters into the "communities." Mark Hachman, "Negroponte: We'll Throw OLPCs Out of Helicopters to Teach Kids to Read | News & Opinion | PCMag.com," *PCMag.com*, n.d., http://www.pcmag.com/article2/0,2817,2395763,00.asp#fbid=yj2DHk4jyPG.

[203] Mexican artist Rafael Lozano-Hemmer makes the case about his artistic practice as a non-representational artistic form by virtue of the fact that he creates scenarios for *participation.* The question that needs to be articulated is what are the forms of representation that are inscribed in staged participatory and collective actions.

Conclusions

An algorithmic tectonics

Reminding us of the inevitably material dimension of architecture, historian and architectural theorist Kenneth Frampton conjures the Greek voice "Tekton" to redeem the structural articulation of architecture —the craft of its *joinery*— as the discipline's fundamental vector.[204] A similarly constructionist sensibility can be used to understand how, within the vibrant cultures of technology production that evolved at MIT during the US-American post-war age, students and researchers formulated a technological discourse of design and design representation premised on the newly-found structured character of computational abstractions. Paraphrasing Frampton, in these discourses I identify the emergence, from within the engineering culture of the *Project*, of an *algorithmic tectonics*: a new imaginary of design and design representation, configured around the structured character of computational descriptions.

By talking about the production of computational representations as a form of *building*, the engineering community developing the *Computer-Aided Design Project* defined a metaphorical arena allowing its members to project tectonic qualities onto computational descriptions, mostly premised on computational abstractions' capacity to configure interrelated data structures indexing multiple kinds of description as attributes.

Building design and construction gave the engineers of the *Project* a set of practices and material substrates they could use as subjects to evaluate the general theories of abstraction defined by the *plex* and the AED languages. In the process, these engineers re-imagined conceptions of design, representation and work, in the language of the machine. This is illustrated by the constitution of design as *problem solving* by the participants of the *Computer-Aided Design Project.*[205]

Crucial to our understanding of the *algorithmic tectonics* is the encoding of perspective mathematics in the computer. Roberts's innovation enabled the representation of three-dimensional objects in the symbolic space of the computer, enabling new claims about the computer as a universal representation machine. I identify in this moment the emergence of a crucial representational tradition based on the intersection, in the computer, of Albertian perspectivalism and computerized data processing.

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[204] "Tekton" means carpenter. Kenneth Frampton, *Studies in Tectonic Culture: The Poetics of Construction in Nineteenth and Twentieth Century Architecture*, ed. John Cava (The MIT Press, 2001).

[205] Echoing Helmreich's observation of artificial life researchers' metaphorical engagement with computer programs as a kind of "second nature" I call this tradition a "second tectonics." Stefan Helmreich, *Silicon Second Nature: Culturing Artificial Life in a Digital World* (University of California Press, 2000).

In a suggestive analysis of the significance of their innovation, French sociologist Bruno Latour suggests that the discovery of perspective geometry, by mathematizing spatial representation and endowing it with scientific validity, constituted a "universal exchanger"[206] distinctive of a Western worldview.[207] Roberts's innovation initiated an environment that accelerates and multiplies the exchanging effect.

Techno-cultural entrepreneurs: engineers as public intellectuals?

> A computer, then, does not simply have an instrumental use in a given site of practice; the computer is frequently about that site in its very design. In this sense and others, computing has been constituted as a kind of imperialism; it aims to reinvent virtually every other site of practice in its own image.[208]

This chapter has shown how the US-American engineers behind the *Computer-Aided Design Project* were not only concerned with the technical production of technological systems, but also with re-imagining entire fields of practice in the language and image of the computer. Coons, Ross, and the other participants of the culture of technology development located around the *Computer-Aided Design Project*, formulated and promoted a sophisticated theory of design linked to the technologies they developed. The purpose of this theory was not only to guide the technical efforts, but to create a new public understanding of design.[209] From this perspective, these engineers were public intellectuals[210] who sought to transform social conceptions of design, representation, and work, both through their artifacts and theories. They were committed to the diffusion of these theories through different outlets —not only to academic, but also to popular cultures. Nicholas Negroponte's adoption of the *Project's* discourses is evidence of the effectiveness of these engineers' techno-cultural entrepreneurship (See frame "The machine in context" below).

Despite the fact that, besides the *Sketchpad*, the technologies developed in the project had only a moderate impact on industry,[211] the technological and cultural entrepreneurship of the *Project* succeeded in

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[206] Realms of reality that seem far apart (mechanics, economics, marketing, scientific organization of work) are inches apart, once flattened out onto the same surface. The accumulation of drawings in an optically consistent space is, once again, the 'universal exchanger' that allows work to be planned, dispatched, realized, and responsibility to be attributed. Latour, "Visualisation and Cognition: Drawing Things Together," 26.

[207] Latour, "Visualisation and Cognition: Drawing Things Together."

[208] Philip Agre, *Computation and Human Experience* (Cambridge University Press, 1997), 131.

[209] This is illustrated by their academic and media advocacy of technology.

[210] The phrase "public intellectual" is used to refer to persons who engage society with theories. By using it to describe the *Project's* engineers I seek to attract attention to the fact that the artifacts and theories they created had effects beyond "merely" functional applications, and in fact transformed social views on what designing, building, drawing, being creative, means. I want, also, to attract attention to the fact that technologies are *discursive*.

[211] Especially in comparison with Douglas T. Ross's previous project, the APT language (in some ways a direct predecessor to the CAD project), which became the industry standard programming language for automated

transforming the popular imagination of design by re-creating its sites of practice in the language of the computer [Figures 12 through 14].

This can be construed as a disciplinarily and epistemologically imperialistic project, premised on the constitution of the computer as a universal representation machine. A Cartesian imagination of the world as a mathematically quantifiable space premised on the newly found algorithmic tectonics of design and design representation.[212]

The machine in context

In *The Architecture Machine* Negroponte used the rhetoric and tools of a nascent techno-scientific culture to formulate a populist project of design where machines are presented as neutral, ethical artifacts, and as democratizing alternatives to the authority of professional designers. I have pointed out how this technological advocacy purports to deliver a social and architectural critique, yet is ineffective because of its failure to consider the crucial role of those who design the machines as important vectors in design and design discourse.[213]

The Architecture Machine is often seen as a foundational piece of Human-Machine Interaction (HMI) literature. This chapter shows how, rather than an isolated product, it's structurally connected to the larger context of technology and culture production of the *Computer-Aided Design Project.* This context was largely shaped by the spirit of discovery of a new engineering culture developing around computers. supported by the US Air Force funding at MIT during the post-war years. A contribution of this chapter is thus a new reading of Negroponte's role in the constitution of a technological design culture during the second half of the 20th century, informed by the structural connections between his pursuits and those of his professors and contemporaries working at the Lincoln Labs as part of the *CAD Project.* The discourses of technological emancipation of design became stories with which later design communities —particularly those rooted in architecture schools— shaped the discourses of design, architecture and technology.[214]

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machine tool control.Bryan Marquard, "Doug Ross, 77; developed APT computer language," *The Boston Globe* (Boston, February 10, 2007), sec. Obituaries.

[212] As Busch points out "both Galileo and Descartes went so far as to argue for the *mathesis universalis*, the notion that the form of the world was itself mathematical. Lawrence Busch, *Standards: Recipes for Reality* (The MIT Press, 2011), 153. Minsky, the MIT pioneer of artificial intelligence called extends this argument and posits that human behavior such as "creativity" can be produced computationally. See Marvin Minsky, "Why People Think Computers Can't", n.d., http://web.media.mit.edu/~minsky/papers/ComputersCantThink.txt.

[213] Other academic architects were concerned with the exploration of new aesthetic realms, opportunities and fields of production. These architects sought to construe the virtual worlds of computers as a realm of its own (the media as subject). See, for instance. Alfredo Andia, "Reconstructing the Effects of Computers on Practice and Education During the Past Three Decades," *Journal of Architectural Education* 56, no. 2 (November 1, 2002): 7–13.

[214] Brian Pfaffenberger suggests that technology makers attempt to change the *social* world in which its technology exists. In this view, the trope of the "personal computer revolution" can be seen as a myth deliberately created by interested parties trying to sell hardware and consolidate a market for technology. The ways in which the users will use the tools, however, is unexpected and rarely conforms to prior conceptions. See Pfaffenberger, B. (1989). The social meaning of the personal computer: or, why the personal computer was no revolution. *Anthropological Quarterly* (61), 39-47.

A key aspect of this role was to broadcast to communities of design and architecture the concepts of adaptability and automation developed by the engineering cultures of the *Project*, helping activate a process of discursive co-construction of design and technology. The constitution, in 1985, of the MIT MediaLab, collects and multiplies this sensibility. However, its examination is outside the scope of this study.[215]

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[215] I hope other researchers take on this question.

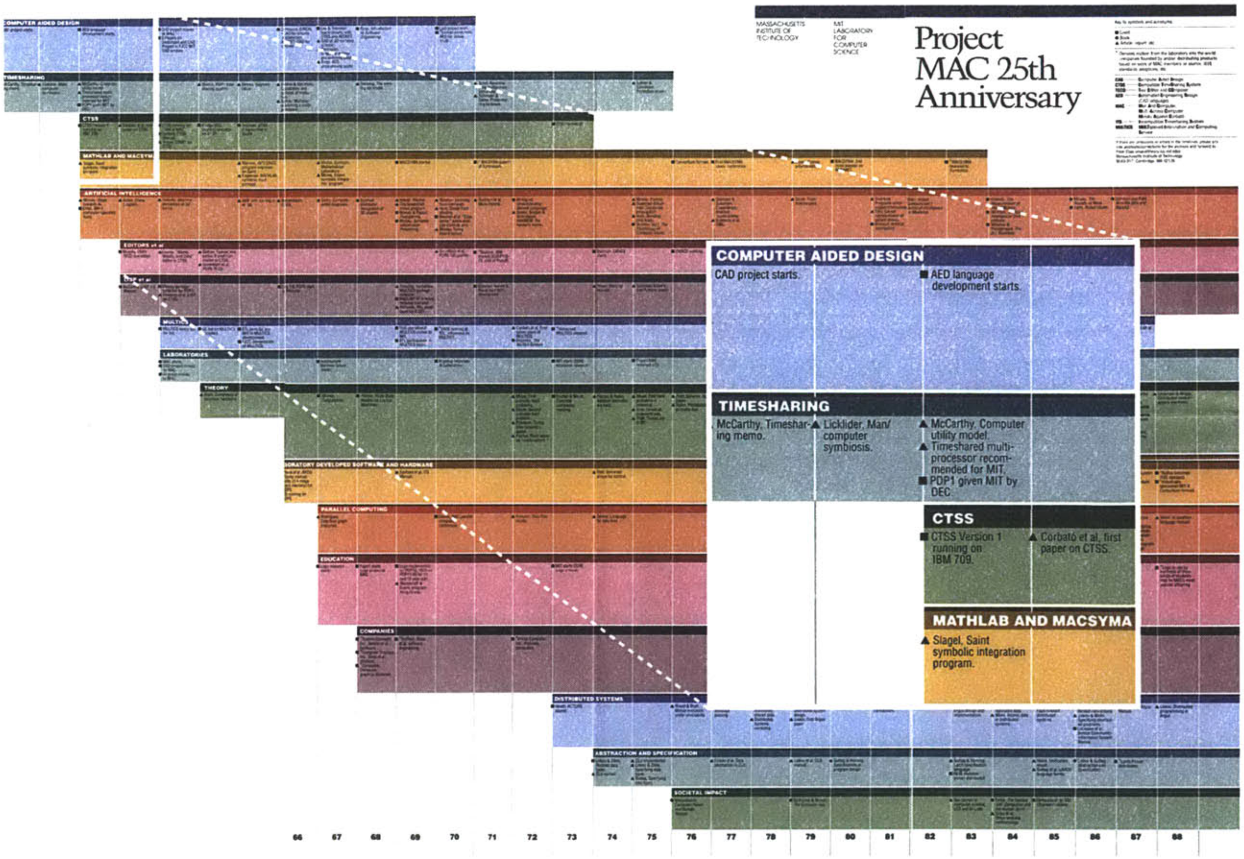
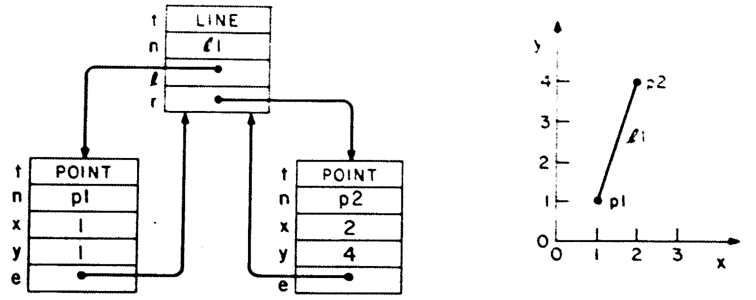


Figure 1. *Project* MAC 25th Anniversary Poster. Courtesy of the MIT Museum. This poster detail shows how in 1963 the *CAD Project* and the Artificial Intelligence Lab become part of the larger MAC *Project*, an interdisciplinary project that transformed into the Laboratory for Computer Science (LCS) in 1975, the predecessor to MIT's Course 6 (Computer Science).



left.end.point(line) $\equiv \ell(\text{line})$

length(line) $\equiv \sqrt{(x(r(\text{line}))-x(\ell(\text{line})))^2+(y(r(\text{line}))-y(\ell(\text{line})))^2}$

etc. for additional properties

Fig. 1 Plex Model

Figure 2. **The *plex* was a theoretical entity developed by the Computer-Aided Design Project engineers. It was intended to represent "anything."**[216]

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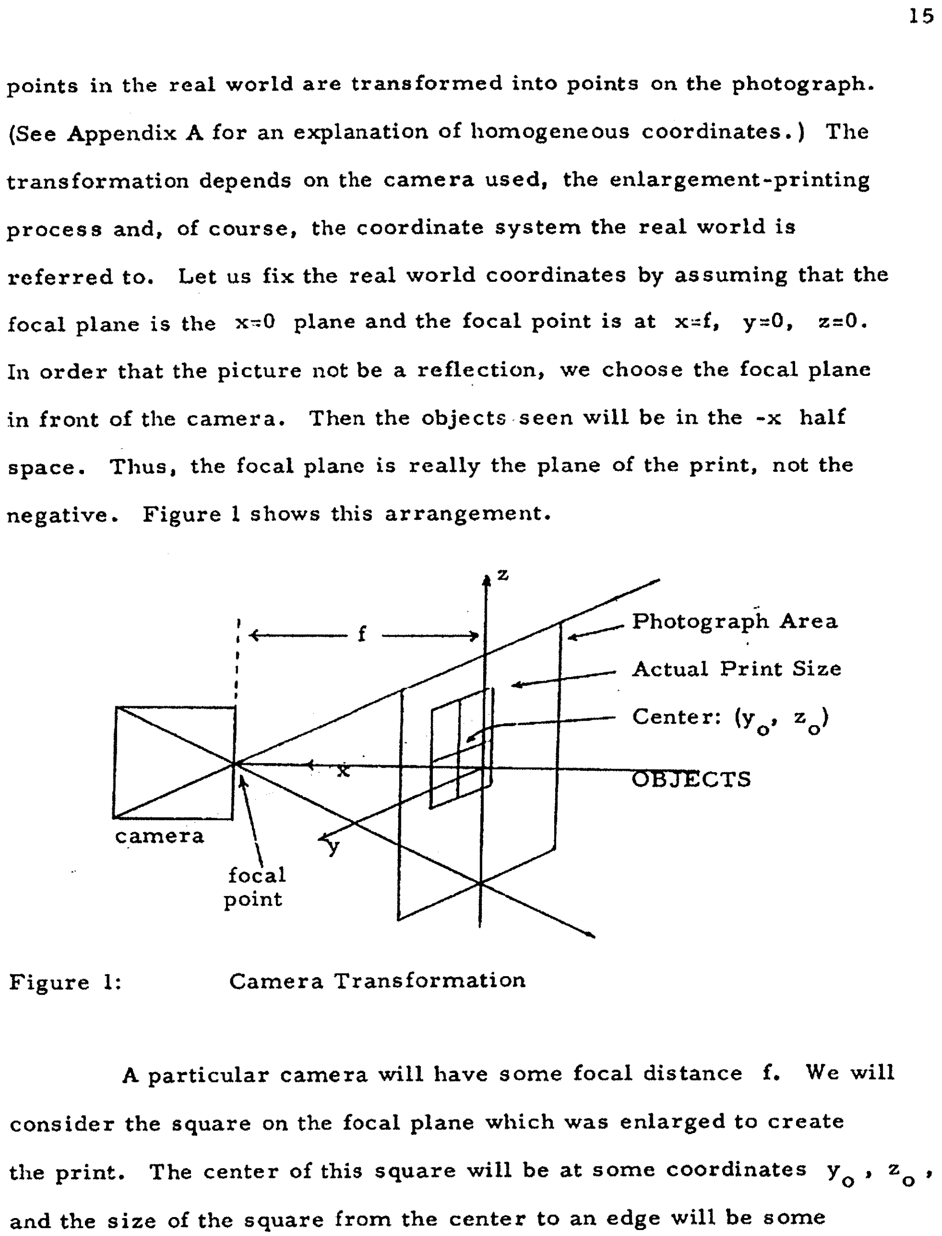
[216] Ross, *Investigations in Computer-Aided Design for Numerically Controlled Production*..



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points in the real world are transformed into points on the photograph. (See Appendix A for an explanation of homogeneous coordinates.) The transformation depends on the camera used, the enlargement-printing process and, of course, the coordinate system the real world is referred to. Let us fix the real world coordinates by assuming that the focal plane is the $x=0$ plane and the focal point is at $x=f$, $y=0$, $z=0$. In order that the picture not be a reflection, we choose the focal plane in front of the camera. Then the objects seen will be in the $-x$ half space. Thus, the focal plane is really the plane of the print, not the negative. Figure 1 shows this arrangement.

Figure 1: Camera Transformation

A particular camera will have some focal distance f. We will consider the square on the focal plane which was enlarged to create the print. The center of this square will be at some coordinates y_0, z_0, and the size of the square from the center to an edge will be some

Figure 3. **Camera Transformation. From Larry Robert's thesis. Courtesy of MIT.**[217]

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[217] Roberts and Elias, "Machine perception of three-dimensional solids," 15.

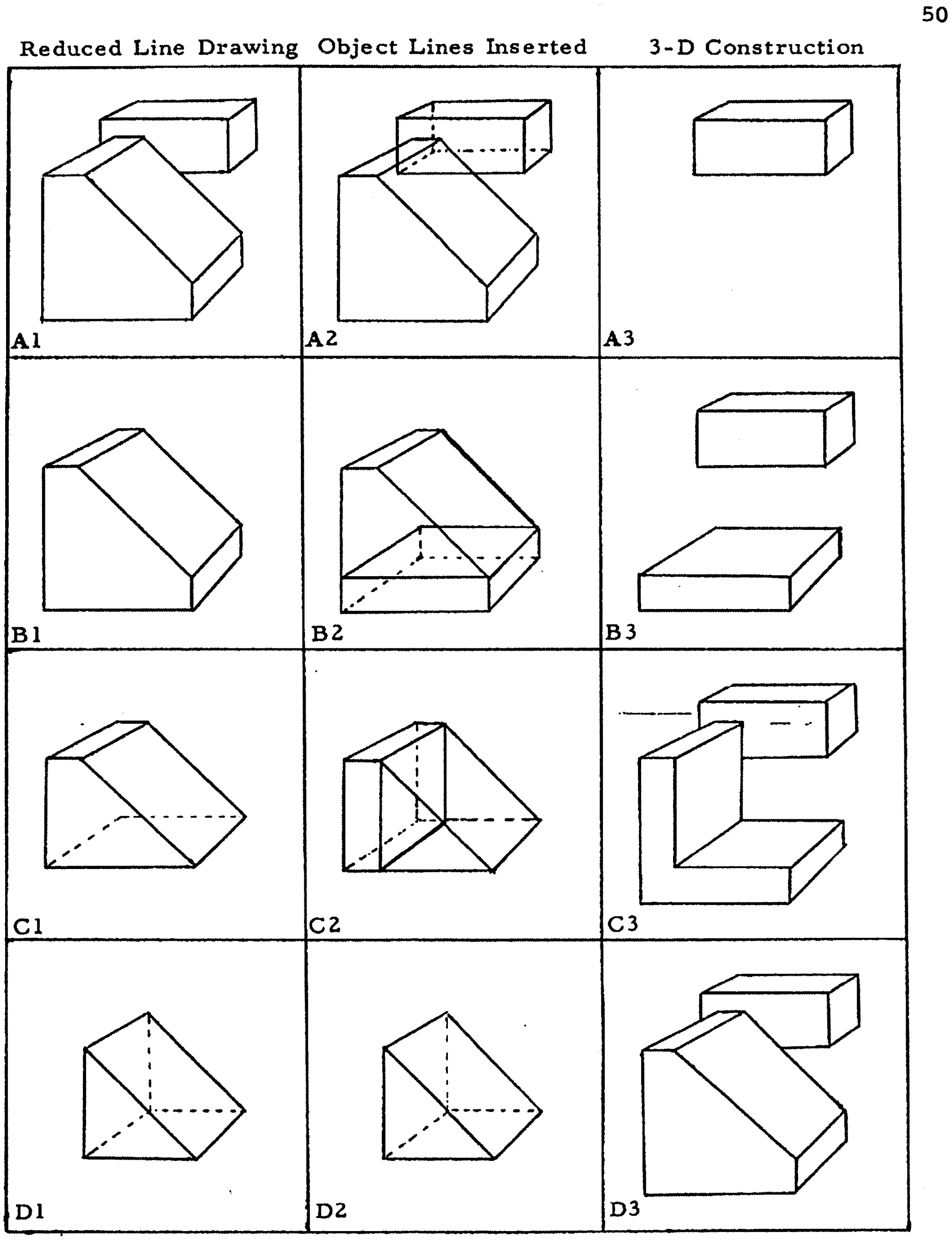

Figure 4: Compound Object Construction: Original Line drawing in A1 is processed to obtain 3-D figure in D3 by sequential recognition and deletion of four models in steps **A**, **B**, **C**, and **D**.

Figure 4. Compound Object Construction. From Larry Robert's thesis.[218]

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[218] Ibid., 50.

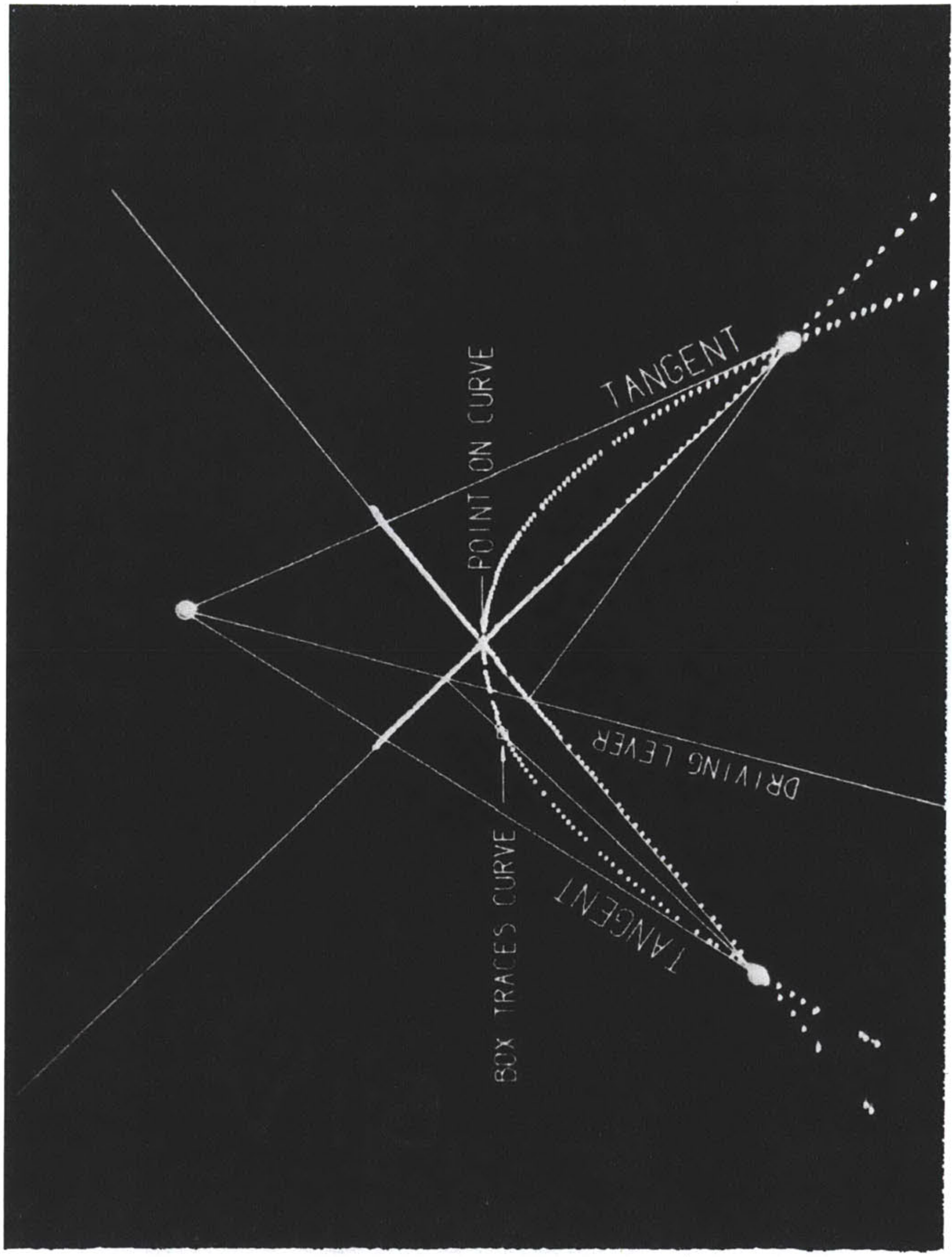


Figure 5. Computer-generated drawing in the ESL console, circa 1963. Courtesy of the MIT Museum.

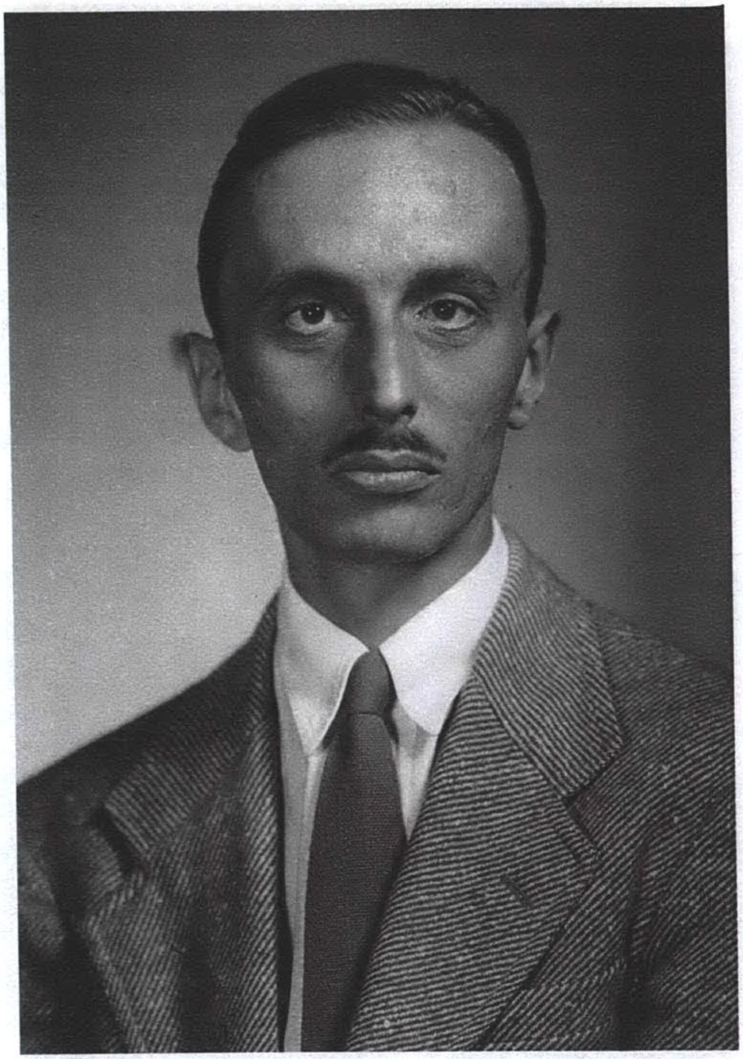


Figure 6. **Portrait of Steven Coons. Courtesy of the MIT Museum.**
Steven Coons was the leader of the Design and Graphics team, and one of the most prominent advocates of computational design.

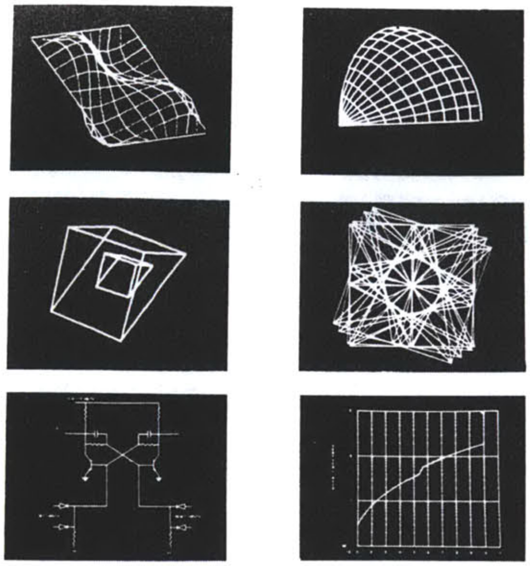


Figure 7. Computer generated drawings in the ESL console, including some of Coons's "patches."

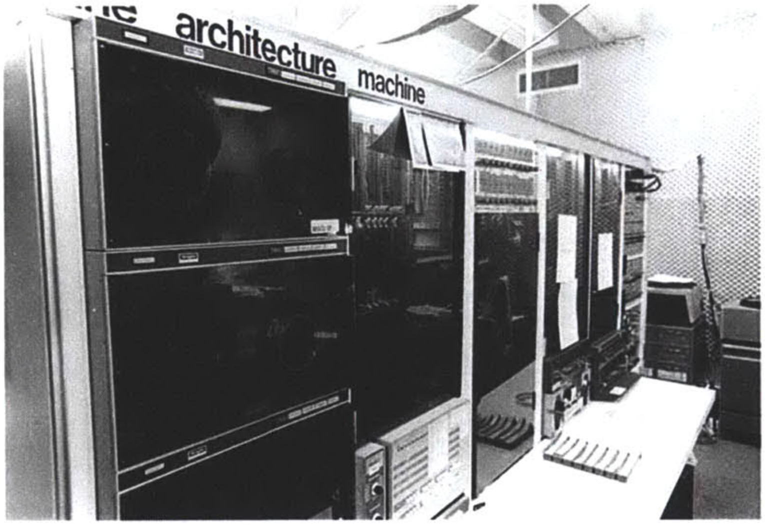
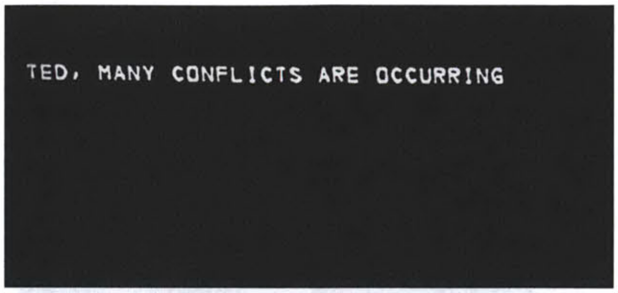


Figure 8. The Architecture Machine. Courtesy of the MIT Museum.



TED, MANY CONFLICTS ARE OCCURRING

Figure 9. **Early CAD system URBAN5 alerts the user "Ted" of design conflicts. From Negroponte, *The Architecture Machine*, 85.**

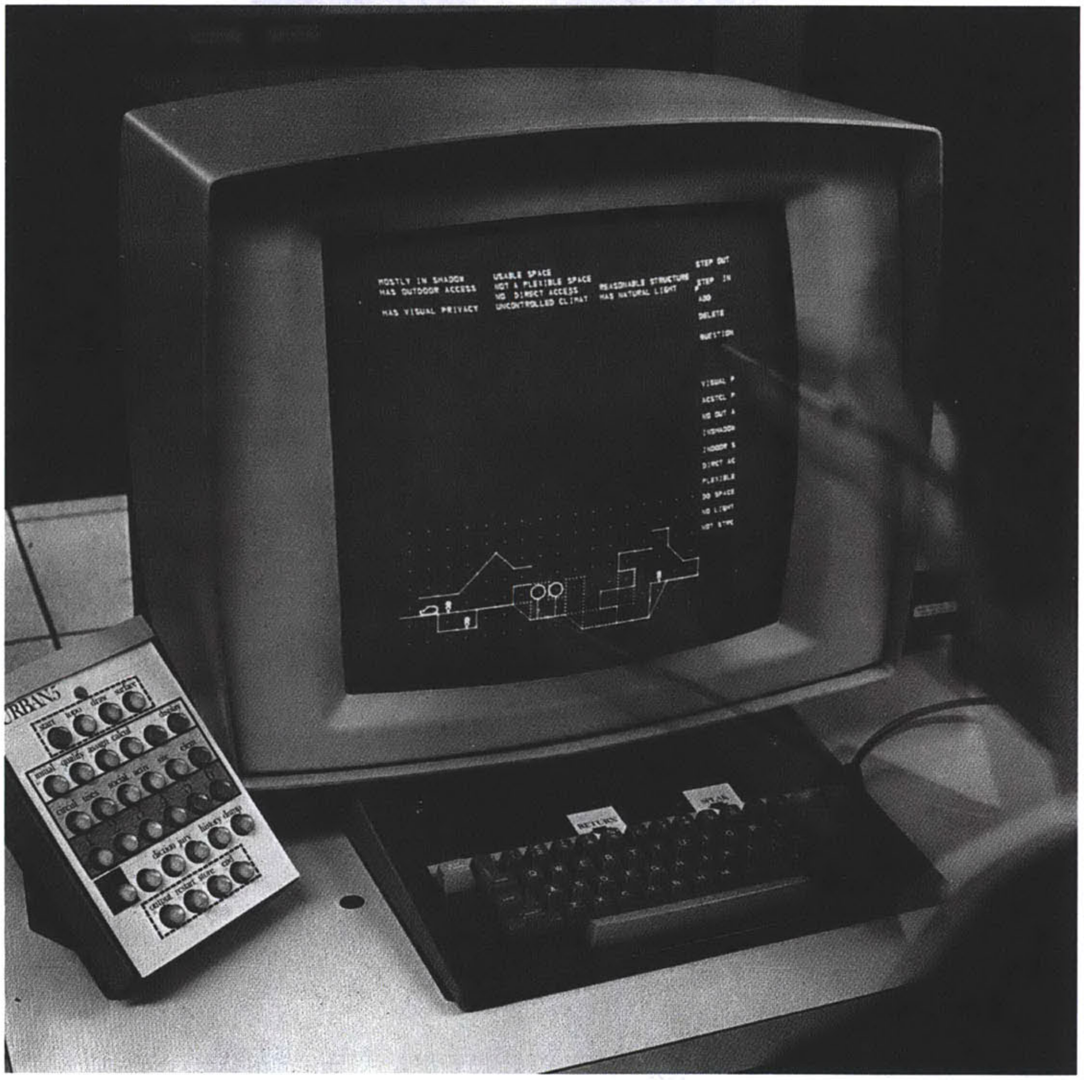


Figure 10. **URBAN5 system. From Negroponte, The Architecture Machine, 80. Courtesy of MIT Press, Cambridge, MA.**

Figure 11. One of the subjects in the "*Hessdorfer Experiment*" interacts with the system. From Negroponte, The Architecture Machine. 56. Courtesy of MIT Press, Cambridge, MA.

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BOSTON, Mass.
Circ. 452,333

MAY 24. 1963

Instant Design Latest Gadget By MIT Men

Those eggheads at MIT are scrambling up a gimmick that will take all the drudgery out of designing anything from an electrical circuit to a jet plane.

The high-domed researchers reported on the progress they're making with SKETCHPAD in a series of five papers they read in Detroit Thursday at the annual Spring Joint Computer Conference of the American Federation of Information Processing Societies.

Once SKETCHPAD is perfected, it will link a man to a light pen, an oscilloscope and a computer.

The man will make a freehand sketch with the pen on the oscilloscope and then let the computer do the rest. When it's through, the finished design will be on the drawing board..

The way SKETCHPAD is designed, it'll be another of man's "slaves." It'll draw absolutely vertical or horizontal lines on command, put circles through precise intersections, show stresses and distortions caused by weights, mesh separate parts, turn a geometrical figure completely around so it can be seen from the rear and solve complex equations as if they were kid stuff."

"On some far off day," said one MIT researcher in his paper, "it may even be possible to call up last year's auto on the oscilloscope, to wave the magic wand of the light pen, and, in a very short time, create the modified version from the old. This will be, in a sense, a mechanization of experience."

They keep on mechanizing experience — and they ain't gonna be much fun left in life.

Figure 12. **"Instant Design Latest Gadget by MIT Men."**[219]

In this 1963 article, the journalist reports on the participation, by members of the *Computer-Aided Design Project* in a the Spring Joint Conference of the American Federation of Information Processing Societies. During the conference, the researchers presented five papers describing the advances on the *Sketchpad*. In the article the journalist echoes the researchers' terms and expressions to describe the *Sketchpad* as a "gimmick that will all the drudgery out of designing anything from an electrical circuit to a jet plane." (...) "it'll be another of man's 'slaves.' It'll draw absolutely vertical or horizontal lines on command..."

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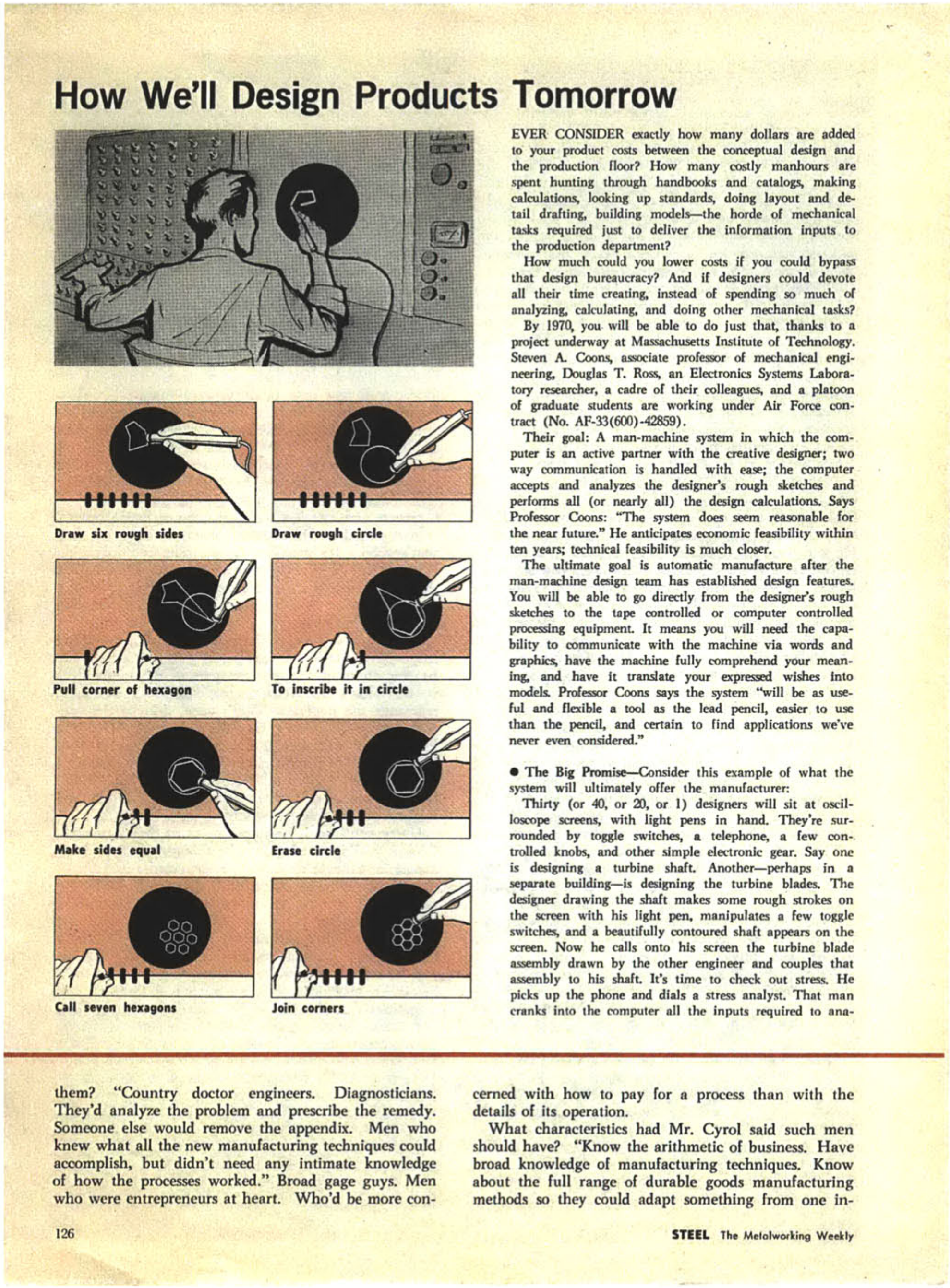
[219] "Instant Design Latest Gadget by MIT Men," *Record-American* (Boston, May 24, 1963).

Figure 13. Ivan Sutherland, working on the TX-2. The *Sketchpad*. Circa 1963.
The innovations by the *Computer-Aided Design Project* were carefully recorded. In this uncut version of a 1963 photographic print, Ivan Sutherland demonstrates the *Sketchpad* to at least two cameras. The camera taking this picture records the interaction of Sutherland and the TX-2 machine. The other camera (we can see part of the tripod and the camera's body on the left side of the picture). Courtesy of the MIT Museum.



How We'll Design Products Tomorrow

Draw six rough sides

Draw rough circle

Pull corner of hexagon

To inscribe it in circle

Make sides equal

Erase circle

Call seven hexagons

Join corners

EVER CONSIDER exactly how many dollars are added to your product costs between the conceptual design and the production floor? How many costly manhours are spent hunting through handbooks and catalogs, making calculations, looking up standards, doing layout and detail drafting, building models—the horde of mechanical tasks required just to deliver the information inputs to the production department?

How much could you lower costs if you could bypass that design bureaucracy? And if designers could devote all their time creating, instead of spending so much of analyzing, calculating, and doing other mechanical tasks?

By 1970, you will be able to do just that, thanks to a project underway at Massachusetts Institute of Technology. Steven A. Coons, associate professor of mechanical engineering, Douglas T. Ross, an Electronics Systems Laboratory researcher, a cadre of their colleagues, and a platoon of graduate students are working under Air Force contract (No. AF-33(600)-42859).

Their goal: A man-machine system in which the computer is an active partner with the creative designer; two way communication is handled with ease; the computer accepts and analyzes the designer's rough sketches and performs all (or nearly all) the design calculations. Says Professor Coons: "The system does seem reasonable for the near future." He anticipates economic feasibility within ten years; technical feasibility is much closer.

The ultimate goal is automatic manufacture after the man-machine design team has established design features. You will be able to go directly from the designer's rough sketches to the tape controlled or computer controlled processing equipment. It means you will need the capability to communicate with the machine via words and graphics, have the machine fully comprehend your meaning, and have it translate your expressed wishes into models. Professor Coons says the system "will be as useful and flexible a tool as the lead pencil, easier to use than the pencil, and certain to find applications we've never even considered."

● **The Big Promise**—Consider this example of what the system will ultimately offer the manufacturer:

Thirty (or 40, or 20, or 1) designers will sit at oscilloscope screens, with light pens in hand. They're surrounded by toggle switches, a telephone, a few controlled knobs, and other simple electronic gear. Say one is designing a turbine shaft. Another—perhaps in a separate building—is designing the turbine blades. The designer drawing the shaft makes some rough strokes on the screen with his light pen, manipulates a few toggle switches, and a beautifully contoured shaft appears on the screen. Now he calls onto his screen the turbine blade assembly drawn by the other engineer and couples that assembly to his shaft. It's time to check out stress. He picks up the phone and dials a stress analyst. That man cranks into the computer all the inputs required to ana-

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them? "Country doctor engineers. Diagnosticians. They'd analyze the problem and prescribe the remedy. Someone else would remove the appendix. Men who knew what all the new manufacturing techniques could accomplish, but didn't need any intimate knowledge of how the processes worked." Broad gage guys. Men who were entrepreneurs at heart. Who'd be more concerned with how to pay for a process than with the details of its operation.

What characteristics had Mr. Cyrol said such men should have? "Know the arithmetic of business. Have broad knowledge of manufacturing techniques. Know about the full range of durable goods manufacturing methods so they could adapt something from one in-

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STEEL The Metalworking Weekly

Figure 14. "How will we manufacture tomorrow?" The engineers in the *Computer-Aided Design Project* reached out to popular media and other fields to promote their technological approach to design. In this article the author introduces the work by Steven Coons and Douglas Ross, and asks the reader "How much could you lower costs if you could bypass that design *bureaucracy*? And if the designer could devote all their time creating, instead of spending so much analyzing, calculating, and doing other mechanical tasks?" (emphasis added). [220]

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[220] "How We'll Design Products Tomorrow," *Steel, The Metalworking Weekly*, January 6, 1964. Courtesy of the MIT Museum.

4. SOFTWARE'S EMPIRE

The practical problem of building design can be formulated, in a general way, as an optimization problem.[221]

Introduction

Outline

In this chapter I consider aspects of the evolution of the CAD industry. In particular, I show how it evolved more in tune with the circumstances of the market, than with the structured representations imagined by the *Computer Aided Design Project's* engineers, or with the robo-utopias of participation and democracy imagined by Negroponte. Moreover, I consider the related but different trajectory traced by the computerized forms of work that made their way into professional architectural practice to contextualize the technology project known in industry as *Building Information Modeling*. Through the voices of prominent advocates, I identify a renewed expression of the 1960s themes of structured representation, technological centrality, and scientific-managerial control over design and construction practices.

Context of adoption

Because of technological limitations and commercial circumstances, the CAD software industry took distance from these *Project's* ambitions, and commercialized instead tools that drew —more modestly— on drafting practices.

Before the wide adoption of Computer-Aided Design software by architects in the 1980s, a few firms used computers to aid in structural and cost-analysis calculations. According to Kristine Fallon[222] the first architectural firm to purchase a punch-card computer system was Ellerbe Associates in 1958 in the US.

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[221] G. Neil Harper, "*BOP*: An Approach to Building Optimization," in *Proceedings of the 1968 23rd ACM National Conference*, ACM '68 (New York, NY, USA: ACM, 1968), 575, http://doi.acm.org/10.1145/800186.810621.

[222] Kristine K. Fallon, *The AEC Technology Survival Guide: Managing Today's Information Practice*, 1st ed. (Wiley, 1997), 150.

However, it was Skidmore Owings and Merril (SOM) —the large US firm based in Chicago— the first firm to develop, in 1967, a program with the intent of "solving" the design of a whole building. The program, called *Building Optimization Program* (*BOP*), optimized building costs against four basic building variables: "Window Wall," "Elevatoring," "HVAC" and "Structural."[223] According to *BOP*'s author, Neil Harper, "the practical problem of building design [could] be formulated, in a general way, as an optimization problem."[224] *BOP* is presented as the first "knowledge-based"[225] computer aided design system for architecture [See Figure 15]. By declaring design as optimization, the *BOP* illustrates SOM's strong commitment to an ideology of production and efficiency.[226] By seeking to account for a range of building variables including cost and materials —not shape— the program is an early precedent of what later would be called *Building Information Modeling*. According to Kristine Fallon SOM decided, in 1969, to develop modular software and sell computing time to other offices.

By committing to a view of design as a rational, quantifiable endeavor —as an optimization— *BOP* illustrates an ontological politics[227] (a becoming) of design as an expression of a scientific-managerial ideology of production and efficiency.

The experimental in-house software development by firms like SOM lasted until the 1980s, when the wide availability of commercial software for architecture —enabled by drop in the price of computing systems— led to the wide adoption of CAD by architects. Relative to other industries like the automotive and aircraft manufacturing, architects were late adopters of computer technology. Because of economies of scale it was more cost-efficient for the car and aircraft industries to adopt the—at the time—expensive hardware and software systems required for displaying interactive graphics. When offices started to purchase the technology from software vendors, most architectural firms became consumers, and not makers, of computer-aided design systems.[228]

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[223] Harper, "*BOP*: An Approach to Building Optimization."

[224] Ibid., 575.

[225] In this context, "knowledge-based" means that the program manipulates entities with a higher level of description. Instead of points and lines, for example, a knowledge-based program allows a user to manipulate graphic elements representing walls, or floor plates. The use of the expression "knowledge-based" may be an indication that the higher-level entities were understood to have semantic knowledge embedded in them.

[226] Firms embraced in-house software development mostly to support accounting, calculations, energy analysis, cost estimation and scheduling. See Fallon, *The AEC Technology Survival Guide*, 150.

[227] See footnote 25.

[228] For historian Robert Bruegmann, cost and efficiency were not the driving factors of architects' adoption of CAD. He suggests that professional architects embraced the computer in the 1980s not because of any of the theoretical reasons advanced throughout the 1960s and 1970s (rationalization of design, socio-technical utopias, or the speeding up of production), but mainly because they were aesthetically attracted to the images they produced. However, this study shows this view is simplistic, and reveals some of the larger forces involved in technology's adoption by architects. See Bruegmann, R. (1989). The Pencil and the Electronic Sketchpad. In e. Eve Blau and Ned Kaufman, *Montreal: Centre Canadien d'architecture/Canadian Centre for Architecture.* Cambridge, MA: MIT Press.

To illustrate the commercial systems that became dominant in the market, I turn now to the distinction between two commercial CAD systems: *AutoCAD* and *Digital Project.* For the purposes of clarity and simplicity, I will characterize each as an exemplar of two modeling paradigms. The first one, *AutoCAD*, illustrates the *geometric* modeling paradigm —a Euclidian design world populated by lines, points and platonic solids. The second one, *Digital Project*, illustrates the *parametric* modeling paradigm —a Newtonian design world populated by forces, attributes and constraints.[229] The Euclidian logic of *AutoCAD* is key to understand the way in which architects adopted CAD, while the Newtonian logic of the *Digital Project* is key to understand the technical dimension underpinning the *Building Information Modeling* project.

Software paradigms

Drafting in a Euclidian universe: a look into AutoCAD

While the MIT engineers who formulated the *Computer Aided Design Project* imagined computational descriptions as the structured combination of geometric data and other kinds of information (cost, analysis information, materials). Here, I discuss how, in contrast with these early ideas, the software industry developed systems that were premised on the more modest aspiration of automating drafting. In *AutoCAD,* drawings are not structured in the sense the CAD *Project* engineers expected.[230]

The widespread use of mass-produced standardized materials such as steel and glass during the first half of the twentieth century had already demanded from architects more precision, detail and volume in building's documentation. The wide adoption, by the 1980s, of CAD-enabled computers appeared to facilitate the digital production, manipulation and storage of building descriptions. Commercially successful CAD tools like Autodesk's *AutoCAD,* greatly contributed to the practical necessity of accommodating and managing the larger amounts of information demanded by construction, becoming the standards of a new industry and transforming architecture practice. John Walker, Autodesk's CEO

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[229] These systems are conventionally known in computational design circles as *parametric.* In Latin *para* means "besides" and *meter* means "measurement." In a parametric modeling software, 3-D representations of geometric elements are typically accompanied by numeric values indicating the element's dimensions. *Parametric* also refers to the associative character of the modeling process: a user can model an object by creating associations between geometric elements, and between geometric elements and numeric values —such as constants, dimensions of other elements, etc. This form of modeling is made possible by the underlying data-structures that represent the geometric elements in the software's database.

[230] From the perspective of pioneers such as Sutherland, AutoCAD drawings can perhaps be thought of as *dirty marks on the screen*.

captures this transformation when he writes of *AutoCAD* "never underestimate the power of a widely distributed tool."[231]

Both the design of its interface and the data structures were designed to re-create the draftsperson's workspace and tools. Its interface was imagined metaphorically as a window looking into a drafting table with an unlimited paper sheet; the commands were named after technical drafting instruments or geometric elements ("line," "ellipse") and eventually arrayed within "toolboxes" with icons pointing at digital representations of analog tools; a system of "layers" was included to reproduce the flexibility of drafting on overlaying sheets of tracing paper.[232] Moreover, its data structures are intended to describe geometric elements at a low level: points, lines, polygons. *AutoCAD*'s data-structures were —and still are— non-hierarchical and non-relational, favoring design operations in which elements get created and stored as single instances —rather than as references to a "template" object. *AutoCAD* is thus tuned to easily represent Euclidian primitives, but not complex associations of elements, like architectural objects. The kind of design operations *AutoCAD* facilitates are based on transformations and operations such as copy, array, mirror, rotate, etc., reflecting the ideology of standardization of twentieth century architecture's means of construction.

As a result of its design, working in *AutoCAD* feels like manipulating digital versions of traditional tools. By creating an affordable computational version of the draftsman's table, the programmers at *Autodesk* brought into architectural practice a series of practical improvements. First, having architectural information encoded in chains of bits —instead of in paper and ink— not only facilitated the storage and recording of design descriptions, but reduced the labor associated with operations such as duplicating, deleting, scaling and rotating elements of the design, allowing for easier transformations of the design documents; second, the possibility of zooming in and out of a drawing made it possible to manage increased levels of detail in drawings.[233] These underlying structures define the ways in which shapes can be manipulated within the system. By enabling certain forms of storage and manipulation, software

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[231] See the Appendix for further detail into the design of AutoCAD. Quote is from: John Walker, ed., *The Autodesk File: Bits of History, Words of Experience*, 3rd ed. (Que Pub, 1989), 300.

[232] Media theorist Lev Manovich uses the term "remediation" to refer to this quality, defining it as "the representation of one medium in another". Lev Manovich argues that the potential of computers to provide opportunities beyond the imitation of earlier media was exploited since the first applications, and discusses cases of computational media pioneers (Sutherland, Kay, Nelson, Englebart) who extended the functionality of their applications beyond the metaphorical. Manovich suggests that in Alan Kay's first drawing tools at Xerox Parc, the interface metaphor worked as a way to lure users into the digital media, yet only to disclose other potentialities — including the extension of the application via programming of new components. See Lev Manovich, "Software Takes Command (book Draft)", n.d., http://lab.softwarestudies.com/2008/11/softbook.html.

[233] See Chapter 3 for a critical discussion about this view of related conceptions of fabrication machinery by Steven Coons and others.

systems like *AutoCAD* condition designs outcomes and the cultures of its practice.[234] The bigger the system, the more difficult it is to modify. By 1986 *AutoCAD* consisted in more than a million lines of C code[235] and embodied more than 70 man-years of development. Its data structures were hard and expensive to modify, and remain relatively unchanged at its core today.[236]

I have discussed how the application that colonized the market of architecture thus fell short to the ambitions of structuredness and centrality formulated by the early CAD pioneers. During a SIGGRAPH meeting in 1989 Robin Forrest, a contemporary of Sutherland who was a visiting researcher at the Project MAC in 1967,[237] was asked to comment on his views on the CAD project. The following excerpt illustrates the CAD pioneers' disappointment at the course taken by the industry:[238]

> So CAD really meant more in 1965 than it does nowadays. It linked into computer-aided manufacture and I feel sometimes that CAD has been somewhat debased by some of the vendors that you used to see on the floor at SIGGRAPH. The 'D' became not design, but drafting. I once asked a vendor what his program could do other than produce drawings. He look[ed] absolutely amazed that you would ever want to do anything other than produce drawings.[239]

Modeling in a Newtonian universe: a look into Gehry Technologies's Digital Project

If the experience of using traditional geometric drafting systems, like *AutoCAD*, stems from the paradigm of drawing on a traditional drafting table, setting up a parametric model "feels" like building a machine. Put in another way, if *AutoCAD* can be thought of as being built on an Euclidian representational paradigm of geometric elements (points, lines) and their transformations, *Digital Project* can be thought of as based on a Newtonian representational paradigm of forces, dependencies, and attributes. *Digital Project* offers an environment similar to a mechanic's table where materials and tools are available for the designer to build mechanisms, rather than fixed representations (the rectangle is not only one rectangle, but potentially many).

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[234] Roll Over Euclid Mitchell argues that "Architects tend to draw what they can build, and build what they can draw." See Mitchell, W. (2001). Roll Over Euclid. In F. J. Ragheb, *Frank Gehry, Architect* (pp. 352-363). New York: Guggenheim Museum Publications.

[235] C is the programming language in which Auto*CAD* is written.

[236] Walker, *The Autodesk File.*

[237] He credits himself with having published the first paper on Computational Geometry. J. Hurst et al., "Retrospectives II: The Early Years in Computer Graphics at MIT, Lincoln Lab, Andd Harvard," in *ACM SIGGRAPH 89 Panel Proceedings*, SIGGRAPH '89 (New York, NY, USA: ACM, 1989), 39–73, http://doi.acm.org/10.1145/77276.77280.

[238] SIGGRAPH stands for "Special Interest Group in Computer Graphics."

[239] *SIGGRAPH '89*, 66.

Unlike *AutoCAD*, *Digital Project* has the capacity to manipulate higher-level descriptions of geometric elements. These systems enforce on the user a modeling process distinctively hierarchical, compared to that of *AutoCAD*, or other *geometric* modeling packages.

The set of associations and constraints defined in the model implicitly declares a design-space: a space of possible variations that is explored in the process of manipulating the model. This particular attribute, of movement, also hints at the mechanical metaphor on which *Digital Project* is based as an engineering tool. Users of *Digital Project* are cast as *mechanics* of designs; they use the system's tools to define design descriptions in terms of relationships and constraints. In turn, they also abide by a certain way of thinking about and going about designing.

When *Digital Project V1R4* opens, a light blue window greets the user and introduces the system in rounded lower caps. Behind the title, a curved shape in a darker shade of blue —*Gehry Technologies's* logo— depicts a wave, or perhaps an unconventional building envelope. Besides the software's name the window indicates GT's url as a sort of signature. After a few seconds the blue window disappears and without further introduction the user is left before *Digital Project*'s empty desktop screen —colored in the same light blue tones and topped by a conventional Windows menu: Start, File, Options, and Help. Until now there's no indication of why *Digital Project* is conventionally referred to as an advanced "parametric" modeling software for architecture.

A look to the "Start" menu yields several items defined within the software as "workbenches" —literally sets of tools intended to facilitate specific kind of tasks. When a "workbench" is activated *Digital Project* changes its interface, opens new toolbars and closes others, shape-shifting into a different system. Selecting one workbench sometimes produces a radical change in the look and feel of the interface. The workbench *2D Layout for 3D Design* under the *Project Center* category, for example, activates a series of toolbars resembling those of *AutoCAD*, in fact providing comparable functionality: ruled paper, orthogonal views, and an assortment of 2-D drafting tools. The *2D Layout for 3D Design* workbench is a little *AutoCAD* embedded within *Digital Project*. Another workbench, *Architecture and Structures*, groups tools that include pre-loaded libraries of parametric —that is, modifiable— versions of architectural elements such as columns, windows, etc. The workbench *Imagine and Shape* —notice the association of imagination and fluid 3-D shapes— contains tools oriented to the "free-form" modeling of surfaces. Other categories contain workbenches for specific aspects of the design/construction process. The *Engineering* category, for example, contains tools designed for deploying technical descriptions of MEP services, such as pipes and electrical networks. The *Analysis and Simulation* category gives access to tools for performing different structural and material tests and for defining "knowledge-based" features such as user-generated rule-sets. Other categories, such as *Project Standards* have workbenches that help connect the model with existing databases of materials and architectural supplies. There's even a *Project Advisor* feature with an icon shaped as a pixilated owl with spectacles —a sophisticated version of the famous Microsoft Word's Clip helper?

While *Digital Project* is a 3-D environment, the standard way of creating objects is to create a 2-D *sketch*. In a *sketch*, a user can draw a quadrangular polygon by selecting the *line tool* with a pointing device and clicking on four points on the screen. With each pair of clicks a line segment will be created, as a rubber band, from one point in the screen to the next. Once the polygon is created, it is "unconstrained:" dragging each point with the pointing device can freely move them, and the lines. The user, however, can start "constraining" it by, for example, selecting two adjacent line segments and specifying in a dialog box that they should be always perpendicular. All of the other polygon components then can be moved freely, like before, but the "constrained" lines now will always form a right angle. The sketch can be further constrained by, for example, specifying that the short sides of the figure will always be greater than one feet, and less than five feet. The result of this process is —voilá— a rectangle of variable side [Figure 16]. Once outside the sketch, the new geometry is visible in the 3-D space (in CAD talk this is called the "viewport"), and can be edited using conventional 3-D tools —such as extrusion, sectioning, etc.— and further associated and constrained with other geometries. In *Digital Project* every element is either a *Part* or a *Product*, words that hint at the system's origin as a tool for mechanical engineering.

Whenever a new element, such as our rectangle above, is created, the software adds it —as a "part," or as a "product"— to an ordered "tree" located to the left of the viewport, which represents the hierarchical structure of the model [Figure 17]. The tree in the user interface lists every element added to the model, and acts both as a way to navigate the model and select its components, and as a way to explicitly record the history of the modeling process. At the software level, this "Product Tree" is a fundamental difference between *Digital Project* and other (non-parametric) systems. In contrast with traditional geometric modeling systems such as *AutoCAD* and MicroStation, *Digital Project* is based on a relational data-structure in which all the geometric elements constituting a model are hierarchically arranged and linked.[240] One of the effects of these linkages for the design process is a clear distinction between a "driving geometry" —a set of geometric elements and parameters that govern the behavior of the whole model— and a "driven geometry" —a set of elements whose behavior is dictated by the driving geometry— within the global and local constraints defined in the model. It is in this sense that designing within *Digital Project* is equivalent to model with constraints and associations,[241] rather than with lines and planes. Such is the "mechanics" of *Digital Project* [Figure 18].

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[240] Rather than hierarchical trees, geometric modeling systems' data structures are more like non-hierarchical lists of elements.

[241] This idea is explored in depth in Axel Kilian, "Design Exploration Through Bidirectional Modeling of Constraints" (Massachusetts Institute of Technology, 2006).

Listening to the Building Information Modeling project

Outline

The preceding section discussed, with examples, the software paradigms serving as environments for computational design practices. In what follows I illustrate how the Building Information Modeling project is presented by 3 key proponents.[242] In my analysis of their accounts, I focus on illustrating aspects of the reconfigurations of design, representation, and work concerning this study. I base my analysis variously on their published works, presentations, and personal encounters.

Andrew Witt: model as center and as global infrastructure

Trained as both an architect and a mathematician, Andrew Witt is the Director of Research at *Gehry Technologies*. Previously, he was Director at the company's Paris office, where he "consulted on parametric design, geometric approaches, new technologies, and integrated practice for clients including Gehry Partners, Ateliers Jean Nouvel, UN Studio, and Coop Himmelb(l)au."[243] Witt commutes weekly from Los Angeles —where the company's headquarters are located— to Cambridge, Massachusetts, to teach a course at the Harvard's Graduate School of Design. In this section, I discuss a lecture where Witt made a concise introduction to BIM technologies and processes,[244] to illustrate crucial questions raised by the imagined centrality of technology to architecture in *Building Information Modeling* discourse. In the lecture, Witt introduced the notion of *Building Information Modeling,* to an audience mostly constituted of architecture faculty and students, as an "unprecedented opportunity for designers" to use a "complete, *highly* complete, 3-D data model" to "comprehensively control the design and construction process through digital tools that allow [for] the tight integration of the intelligence, analytics, and constraints of virtually all aspects of the project."[245] Witt further described the emerging form of practice as "concurrent

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[242] The 3 subjects were chosen because of their role as key promoters —and developers— of the *Building Information Modeling* paradigm within architecture academic and professional communities.

[243] From a profile included in the announcement of the talk: Witt, "Concurrent Design."

[244] The lecture was part of the Harvard Graduate School of Architecture's lecture series, and was open to the public. The audience was mostly constituted of architecture faculty and students. {Citation}

[245] Ibid. The emphasis is mine. Witt reinforced the theme of technological centrality: "Model-centrism —rather than drawing-centrism— is back with a vengeance courtesy of 3-D modeling tools (...) designers have never been so invested in the realization of complex geometry. The encapsulation and automation of mathematical methods in software (...) offers a new transparency in the architectural manipulation of mathematics. As designers [are] increasingly de-constructing and building these tools, building their own tools, they build also fluency in the underlying mathematics, and find novel formal applications to them. Competing theorizations of this trend [are] actually testing the fertility of a new rigor in design geometry." Noam Andrews and Andrew Witt, "Building

design," as an integration of design and construction enabled by the circulation of design information across global digital networks. The following excerpt captures this form of practice:

> [Concurrent design is the] process of saying: "OK, design is no longer separate from construction, from fabrication." [Instead, it's about] bringing very high fidelity information downstream, so engineering requirements, process constraints, as well as ensuring high fidelity information from early in the process. It's a very simple idea."[246]

With a world map showing "the global distribution of the top ten architecture firms in the world," Witt contended that most "high-profile" design firms are located in the Euro-American Northern Hemisphere, while most of the construction is happening the Middle East and China,[247] adding a geographical dimension to the design and construction split. The following excerpts illustrate the case for a new form of communication to satisfy the demands of the increasingly globalized landscape of practice:

> [Architecture and building practice is] much more global than it's ever been ... you have all these people you need to collaborate and work together with around the clock, who have very specialized knowledge, increasingly specialized... and we need to put that information together in a much more proactive way. So we need to *reinvent this dialog.*[248]

> Communication that happens in this process can be so... pathological, there are so many entrenched interests and barriers to the communication of this information that it really takes nothing less than a *radical process change* in order to affect this sort of process.[249]

The "reinvented dialog" and "radical process change" is thus premised on the reduction of geographical and disciplinary distances by digital information of practice —the transformation of activities and their outcomes into information. In one slide, Witt represents this "reinvented dialog" with a diagram of the process where a cube representing a digital model is surrounded by a number of actors of the design and construction process. Arrows flowing from the cube connect to all the actors [Figure 19]. Conventionally, the schematic structure of a project's organization is shaped as a pyramid: the client and developer, in that order, are at the top; the architects, contractors and subcontractors, at the base [Figure 20]. Witt's diagram replaces the vertical hierarchy with a centralized one: a ring of actors organized

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Geometry - Gallery Talk - YouTube", February 28, 2012, http://www.youtube.com/watch?feature=player_embedded&v=kbeU87UIzjc.

[246] Witt, "Concurrent Design." See also Andrew Witt, Tobias Nolte, and Dennis Shelden, "Large-scale Concurrent Design: The Case of Fondation Louis Vuitton," in *Proceedings of the Design Modeling Symposium*, n.d.

[247] This gives the Albertian split a geographical dimension. Simplistically, design is West, construction is East.

[248] Witt, "Concurrent Design." Emphasis mine.

[249] Ibid. Emphasis mine.

around a center, occupied by the digital model. The model's central position in the diagram, and the arrows connecting it to all actors, illustrate the imagined role of technology in design and construction as a communication hub for all participants of the design and construction process.[250]

In the following excerpts, a question posed by a student after the lecture forces Witt to address a crucial contradiction between the business of practice, and the idea of design empowerment he used to frame the BIM project at the start of the lecture.

> STUDENT: I'm thinking of this idea about the empowerment of the architect. Because it's not so much about, is it more, I mean… It seems to be more about the transference of information, and in the software... It doesn't necessarily have to be the case that the architect is empowered... It's about who's controlling the cloud and who's controlling the system.
>
> WITT: Well, the party that controls the system is definitively the one… the one that… You know, the one that's in charge. Of course we are sympathetic to the architect [laughs]. I mean, I for one hope that's the architect! Right? But it's up for grabs, right? I mean it's… It's… The game is sort of… And I think that at some level there are a lot of very intelligent… well, you know… Fairly intelligent contractors who are… [Witt pauses, jokingly, and the audience laughs]… Who are … into this sort of thing. In a way, Gehry Technologies in some level is… somehow neutral there… [pauses] But, you know... I, for… I… straight from the GSD,[251] I certainly hope it ends up being the architect. But on some level yes, I think it's... The architect can leverage these relationships. I don't think necessarily the technology empowers this party or the other, but I think the architect is well positioned to… [pauses and smiles] That's totally fair![252]

In Chapter 3 I discussed how, during the days of technological design advocacy by members of the *Computer-Aided Design Project,*[253] architects were presented with digital technologies as forms of creative empowerment.[254] As my discussion of Negroponte's techno-populist discourse of design shows, this notion is often premised on the deletion of the roles of technology's authors and of the politics of technological arrangements. In the exchange between Witt and the student, the diversity of forces shaping the contemporary professional and economic landscapes of practice comes into view. In the new geography of design, technology is both center and infrastructure of design. In Witt's account, the architect's place in this newly revealed geography is presented as a matter of *sympathy* —a concession by the "party in charge." As a professional architect, Witt understands the conflict well. The center of the diagram, and

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[250] This is a conventional representation of BIM.

[251] Harvard Graduate School of Design.

[252] Witt, "Concurrent Design."

[253] See Chapter 3.

[254]

the arrows connecting it to the peripheral ring of trades, not only represent a change in the flow of information, but a new form of organization of practice around the social and technological infrastructures of digital models: "The party that controls the system is the party in charge." In this case, the organizations developing and commanding the digital infrastructures of design, like *Gehry Technologies,* and those who can afford to hire them.

Chuck Eastman: towards unmanned design systems

Chuck Eastman is one the earliest and most articulate advocates of what has come to be known as *Building Information Modeling.* With admirable persistence, Eastman has researched the potential of relational databases and object-oriented languages to reconfigure the production of buildings since the early 1970s to today, with academic appointments in UCLA, Carnegie Mellon, and more recently at the College of Architecture at Georgia Tech[255] as the director of the "Digital Building Lab." One of his earlier propositions, for instance, is the *Building Description System* (*BDS*), a software prototype meant to "[replace] drawings as the primary description for design and construction of buildings."[256] Echoing the nascent paradigm of object-oriented programming, the project's description posits a view of design as the symbolic manipulation of assemblages of discrete objects endowed with data attributes: "an adequate description of a physical system is a specification of a set of elements together with their relative locations and that all other relations may be identified from these primitives[257]." Like his almost-contemporaries at the *Computer-Aided Design Project* at MIT[258], Eastman sought to define the most flexible and adaptable system imaginable. He thus presents the *BDS* not as a problem-oriented design system, but as a "general description system, allowing for definition or alteration of any possible element, and very general analytic and drawing routines."[259] The *BDS* was thus equipped "means to produce drawings of their arrangement and to analyze their performances."[260] As an example of how the system could analyze a design, Eastman suggests what today is known as "clash-detection:" the "automatic determination of spatial conflicts" resulting in "a single database useful for communication, analyses, coordination, and fabrication."[261] Eastman conceived the system's basic component description as an assemblage of three separate parts: a

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[255] "Digital Building Lab @ Georgia Tech: About Us," Academic, BIM *Resources @ Georgia Tech*, n.d., http://bim.arch.gatech.edu/content_view.asp?id=509.

[256] C. Eastman, J. Lividini, and D. Stoker, "A Database for Designing Large Physical Systems," in *Proceedings of the May 19-22, 1975, National Computer Conference and Exposition*, AFIPS '75 (New York, NY, USA: ACM, 1975), 603, http://doi.acm.org/10.1145/1499949.1500073.

[257] Eastman, Lividini, and Stoker, "A Database for Designing Large Physical Systems."

[258] See discussion about the Plex.

[259] Eastman, Lividini, and Stoker, "A Database for Designing Large Physical Systems," 603.

[260] Ibid.

[261] Ibid. This kind of analysis is now called "Clash detection" or "Conflict detection" and is a staple of modern BIM systems.

topology, a *geometry*, and its *attributes*. A "components library" would store both the system's pre-defined components, and the user-defined ones. Like modern software, rather than storing a large number of independent descriptions, each component "deployed" onto the design is a reference to the component's template in the library [See Figures 21 and 22]. The *BDS* was written in a system-building language called BLISS, developed at Carnegie Mellon University —where Eastman was then based. Its size on disk was 120Kb —approximately one fifth of the file size of the Word document containing this dissertation.

Eastman understood, like Sutherland, that the users of the system would have to be of a new kind. In a 1977 paper, Eastman speculated about the way in which designers using the system would change and adapt to the technology:

> While we do not see designers becoming programmers (or vice versa) overnight, we hope that such a system will allow the naive user to find the system useful with minimal learning and that as he or she demands more powerful capabilities, they can be easily learned in small increments. We see this as a way of reducing the gap between these two classes of people.[262]

In 2008, in a guest talk entitled *Was Alberti wrong? The Separation between architectural design and construction* at the MIT Department of Architecture, Chuck Eastman posited the view that *Building Information Modeling* is to "heal" Alberti's design-construction divide.[263] The presentation was an illustration of the same research principles explored in his 1975 *BDS* project. A software application encodes a building's geometry, zone regulations, and information about materials and construction, into a single project database. Encoded in the database as rules, the building codes and other restrictions can be automatically checked for compliance —and therefore help design teams produce a valid design. The information about construction and materials can be used by the system to automatically generate construction documents. Eastman proposed that the system's capacity to encode information about materials, costs and regulations, collapsed the Albertian divide between design and construction. As a case study, Eastman's team explored the design of federal courthouses[264]. The detailed construction documentation produced by the system, Eastman argued, can reduce the need of skilled labor during both design and construction phases, thus

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[262] Charles Eastman and Max Henrion, "Glide: a Language for Design Information Systems," *SIGGRAPH Comput. Graph.* 11, no. 2 (July 1977): 25. For a discussion of the new professional roles emerging around computation and simulation, see Yanni Alexander Loukissas, *Co-Designers: Cultures of Computer Simulation in Architecture* (New York: Routledge, 2012).

[263] Sixteenth century architect and scholar Gian Battista Alberti spoke of the architect's need for a skilled craftsman to execute his designs, establishing a long-standing tradition of separating construction from design work. This division, historians have argued, has been instrumental for the definition of architects' authority as a social and professional group. See Chapter 2.

[264] These buildings,' are a convenient exploration for the BIM project because, first, their designs are governed by long manuals of requirements and specifications. Second, they need to be deployed across the entire US territory. Also, they are commissioned by a well endowed patron.

helping reduce the US construction industry's dependence on human labor —and, in particular, its reliance on "illegal immigrants."[265]

The image of a semi-automated construction recalls Coons's idea about "perfect slaves" —slavish servants performing the drudgery of physical labor; mechanical versions of Alberti's skilled craftsman. Eastman's proposition, however, is imagined differently. Instead of Coons's (naïf) liberalizing rhetoric of mechanically supported creativity, Eastman's enacts a managerial desire of efficiency and productivity — with an ethno-national component. This desire is enacted by designs being *unmannedly* deployed into — materialized *into*— the world.

Eastman's uniquely focused academic career is an illustration of the enthusiasm that, since the onset of the computer age, led engineers and technologically minded architects to re-imagine design practice through computers. In Eastman's technological imagination, design is re-conceptualized as the definition and manipulation of discrete objects representing architectural elements, and their attributes, in the digital space of software. Like Negroponte[266], Eastman took issue with the "fallible" subjectivity of human designers, but, unlike him, Eastman doesn't seek to coat the effort to remove subjectivity with liberatory tropes of socio-technological emancipation. Eastman uses instead, unapologetically, scientific managerial tropes of efficiency, automation, labor costs, and ethno-national political geographies of work. Moreover, through technology, he seeks to establish new forms of professional legitimacy for architects in an increasingly uncontested techno-scientific society.

Eastman's career-long technological proposition illustrates the convergence, in architecture, of the two defining personas of the 20th century: the scientific manager, and the engineer.

Dennis Shelden: drawing the boundaries of design

Dennis Shelden is a key figure in the development of both *Digital Project* and *Gehry Technologies*. Before obtaining his doctoral degree in Design and Computation from MIT, [267] Shelden obtained degrees in architecture and civil engineering. Shelden based his dissertation on his work as a computational specialist at Frank Gehry's office, *Gehry Partners*, in Los Angeles.[268] Since the constitution, in 2000, of *Gehry Technologies* as a body independent from *Gehry Partners,* he has led the firm's technology efforts, combining this with a position as an Associate Professor of Practice at the School of Architecture at MIT.

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[265] Eastman also speculated that this information could even be made "machine-readable," so that robots could put the building together unmannedly.

[266] See previous chapter.

[267] This group also houses my graduate student work and this research.

[268] Dennis R. (Dennis Robert) Shelden, "Digital surface representation and the constructibility of Gehry's architecture" (Thesis, Massachusetts Institute of Technology, 2002), http://dspace.mit.edu/handle/1721.1/16899.

In his courses, Shelden has used *Digital Project,* as well as other software systems, to introduce architecture students to mathematical forms of spatial and material description. Instead of using computation as a generative, form-making strategy (a common trend among computational design educators), Shelden asks students to see computers as instruments to encode and explore the physical properties of material systems. His role within Gehry's practice may have informed this pedagogical approach. In what follows I refer to a conversation with him at MIT, to explore aspects of the contemporary theories of design evolving around the digital environments of *Building Information Modeling.* In the excerpts immediately below, Shelden discusses his first visit to Gehry's office —while still a student— recalling being impressed by the manual work on physical models by the architects.[269]

> When I got out to Gehry's, there was a whole other epiphany that really is about design, and (...) the relationship between design, process, and making. I had never been exposed to that; I had always been exposed to the analysis part (...) I knew computational fluid dynamics and finite element analysis and all these things, and 3D modeling, and rendering (...) and then you get out there [to Gehry's office] and they're doing this *amazing stuff with materials...*[270]
>
> Design is about physical things.[271]
>
> [Software] has absolutely nothing to do with design, but with the communication of design through the collaboration, through the community.[272]
>
> Historically, [software was] not about the design process but about the production process; everything through documentation of design intent and the satisfaction of code, communication, contractual communication, and then realization and fabrication in the field.[273]

In these excerpts, design is identified with the physical exploration of materials, while software is construed as an instrument for the documentation, analysis and simulation *of* design —activities seen as peripheral to and supportive of design. Once design is *encoded* in the software, it is no longer imagined as an activity, but as information to be processed and circulated through the metaphorical "pipes" of digital networks. Crucially, in this "infrastructure" theory of design software, the concepts of technology and design are mutually constitutive *and* exclusionary.

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[269] Remarking on the sharp contrast between Gehry's form of design practice and his training as an architect, engineer and computation expert at MIT.

[270] Dennis Shelden, "Interview with Dennis Shelden," Digital Recording, March 3, 2010.

[271] Ibid.

[272] Ibid.

[273] Ibid.

The exclusionary aspect is illustrated nicely in the following excerpt. In it, Shelden describes the role of *Gehry Technologies* as "everything but" design: as a tool to aid the documentation and communication like a scaffolding[274] to create a "continuity of information" between disciplines.

> Gehry Technologies has grown to be sort of the organization that does everything but design. We really are about the extended process, and how you use technology to bridge these different disciplines and create a continuity of information ... The building process has lots of rich interactions within organizations and very thin pipes between them.[275]

Shelden sees the highly idiosyncratic and diverse communicative practices of the building industry as opportunities to build a more efficient information infrastructure. While the technical practice of *Gehry Technologies* manages the communications infrastructure, design is located within other forms of practice, including physical model-making and drawing.[276] This exclusionary relationship can be understood as an expression of the *Albertian split* between design and construction in the professional and legal cultures of the AEC industry. While scholars of practice have repeatedly challenged the peripheral location of technical practice in design discourses,[277] Shelden's discourse shows its practicality for *Gehry Technologies*: locating their practice in the periphery of design is fundamental to abide by contractual boundaries and cultural conventions —and perhaps more importantly, for establishing a strong market proposition.

"Design" and "technology" exist, in this discourse, as mutually constitutive artifacts. In other words, the boundary between the technical domain of digital information and the material domain of design, helps define both. Prior to its translation into the computer, design is imagined as a tangible material exploration: a practice.[278] Once this phase is finished, the design is "frozen" and re-imagined as an inert entity requiring documentation, communication, analysis and (finally) materialization. In the dual body of

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[274] Supportive and external, like a scaffolding. See the scaffold metaphor in the Introduction.

[275] Shelden, "Interview with Dennis Shelden."

[276] In this excerpt, Shelden concisely explains architect's limited role in the economy of construction, and the idea of design as an additional service: "There's [design] concept but you don't get paid, that's an additional service right? So there's 20%, 20%, 40%, 20% of the fee, which in aggregate is... about 5% of the construction cost. So, if you take 5% so 1% of the total cost of the building is design, right? And 1% is figuring out the systems. And if you look at how architects get paid, right? That's where they get paid. And ... I shouldn't be pejorative, but this is largely documentation. So this is [points at the doodle in the notebook], this is everything that ... architectural students and theoreticians think architecture does. And this is ... where they actually they get paid. And a lot of times they don't even get paid for this." Ibid.

[277] See, for instance Lucy Suchman, "Organizing Alignment," *Organization*, 2000: 311-327. Kathryn Henderson, *On Line and on Paper: Visual Representations, Visual Culture, and Computer Graphics in Design Engineering*, Inside Technology (Cambridge, Mass: MIT Press, 1999). And more recently Loukissas, *Co-Designers.*

[278] There is a de-coupling of design as both a material and immaterial practice/object. On one hand design can be construed as *something* to be communicated via digital representations (that is, as a signifier, or as something for which the digital representation acts as an index). On the other hand design can be construed as the object and practice of the (non-digital) representation itself. Once "encoded," it is imagined, in an information-theoretical tone, as *information.*

practice formed by *Gehry Partners* and *Gehry Technologies*, the software *Digital Project* constitutes the disciplinary boundary between the two domains, and the social boundary between those who design and those who rationalize, document and communicate the design.[279]

While the stark distinction between design and documentation is enforced by legal and cultural contexts, there are moments in which it blurs. During one of his classes, Shelden invited one of his colleagues to present a case study —a real project where BIM and *Digital Project* were used as design and construction coordination methods. In an exchange with his colleague and the class after the lecture, Shelden gave insight into a reconfigured equation in which the boundaries between design and construction are contested and blurred. At the end of the presentation, a question was asked about whether there had been a "feedback loop" between the design team and the BIM team that resulted in changes to the "original" design —if the building's shape had changed during the process of "encoding" the architect's representations[280] into *Digital Project.* The consultant didn't hesitate: "there was not a lot of going back and forth, we were just rationalizing the geometry provided by the designers in the design model ... the architect's team was always 'in charge' of the design." At this point, Shelden intervened and, pointing to the *Digital Project* model projected on the wall, said forcefully: "*This* is the design: the architect's model is just an intent; a *design intent.*"[281]

By highlighting the design team's work as "intent,"[282] Shelden's move reframed both the consultant's portrayal of their work as "merely" technical, and the dualistic (design-construction) frame implicit to the question. Under this view, the technically intensive work of geometric rationalization and workflow management developed by the BIM team was the "true" design —or at least an integral part of it. The result of this move is to expand the definition of design to include design's *means and methods,*[283] a forceful attempt to blur the distinction between the realms of design and construction, or the *Albertian Split.*[284] The effects of this blurring are a re-definition of the disciplinary boundaries that separate architects and engineers, and a reconfigured politics of architectural authorship where a technologically enabled collective of actors replaces the architect as the sole mastermind. With the move, Shelden colonizes design —rhetorically at least— for the technical practices of organizations like GT.

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[279] As shown by Loukissas in a study of simulations at Arup, software systems can serve as instruments of boundary demarcation between professional groups. See Loukissas, *Co-Designers.*

[280] Typically, drawings and non-BIM digital models.

[281] In the legal language of architectural contracts "design intent" refers to a specific stage of the design construction process where no structural or technical information is present. See [AIA REF].

[282] Design intent is a contractual term referring to the architect's descriptions. Besides its contractual dimension, the term etymologically connotes what is unfinished, embryonic, or projected.

[283] A phrase often used in industry and contracts to refer to the domain of construction.

[284] I discuss this in Chapter 2 by reviewing critical accounts of practice by Cuff, *Architecture.* and Larson, *Behind the Postmodern Facade.*

This redefinition of design deserves special attention, as it contradicts traditional premises of the architect's academic training.[285] By locating design within the technical practice of BIM's digital descriptions, Shelden's move evokes the attitude of nineteenth century US-American architecture culture —as described by Johnston: a constant negotiation and tension between authorial aspirations and a pragmatist, business ethos.[286] These reconfigurations are premised on the centrality and universality of the technological infrastructure of software and process.

There are thus rich tensions in Shelden's representations of design and technology. While during the conversation Shelden places technology as an infrastructure for design ("everything-but design"), in the exchange with his colleague in class he identifies it, forcefully, with the design itself ("*this* [digital model] is the design"), making a powerful claim about design as an expanded process including stages of documentation, analysis and simulation. The narratives differ in the value they assign to human subjectivity. During the class —echoing Eastman and Negroponte— Shelden construes technological agency as a way of contesting the primacy of the architect as the project's mastermind. In the conversation, more in tune with the foundational narrative of GT, the subjectivity of the human designer is at the root of the technological effort: it's because Gehry's unconventional designs have evolved into culturally relevant artifacts that new technological approaches and solutions are put in place to bring them into completion.[287] The duality of the proposition is worthy of notice. It illustrates the transformative tensions, exerted by technological changes, on the cultural and legal disclosures of architectural practice.[288]

These tensions come into light in the constitution, in 2000, of *Gehry Technologies* as a separate organization from *Gehry Partners.* In the following excerpt, Shelden explains how the managerial advantages afforded to *Gehry Partners* by their innovative approach to software, enabled the architects to control larger portions of the design and construction process. The increased managerial control brought the architects too close to stretching outside the conventional contractual boundaries of their practice:

> "What we were doing as an architecture firm, in terms of defining the process of others, was a very dangerous thing to be doing from a contractual perspective (...) it's the (...) architect and means and methods problem, right? So, in order to

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[285] And in many ways closer to the heteronomous understanding of architecture advocated by critical observers of architecture like Dana Cuff and Magali Larson.

[286] And the subsidiary tensions and debates between building mechanics and architects. I consider this in Chapter 2, in particular around the historical account by Johnston, *Drafting Culture.*

[287] See discussion about the "organization of the artist" in Chapter 1.

[288] While the sphere of design is construed as sacred through contractual and cultural taboos, it gives purpose to the *profane* sphere of technique —a world of "hard outcomes you can rationalize towards." Despite constituting two companies, Gehry's name and directorship over both *Gehry Partners* and *Gehry Technologies* preserves an allure of individual mastery.[288] Metaphorically, body and scaffold, respectively, of architecture.

> impact what other people were doing we were doing things that, narrowly, architects are not supposed to be doing..."[289]

The constitution of *Gehry Technologies* illustrates the effects in industry resulting from the organizational transformations fostered by the implementation of digital modeling environments and *Building Information Modeling* systems and processes.[290] Crucially, software's capacity to exert an increased managerial control exceeds the cultural and contractual roles conventionally attributed to architects. This capacity is expressed in the "infrastructure" trope outlined above: the notion of technology as both a central hub and infrastructure (not as a tool) that distributes and processes design information. A scaffolding for design. In the frame below, I discuss Shelden's conceptualization of design "in" the software.

Designing in the software

Not all software systems are explained in terms of infrastructure. Back in our conversation, other systems appeared to enact a different role. In the following excerpt, Shelden discusses the 3-D modeling software *Rhinoceros* as a better support for design because it enables users to manipulate shapes in a way that resembles the manipulation of physical objects in the world. In *Rhinoceros*, a user seeking to model a building component can simply stretch, "pull and erase things:"

"Most of the software that's out there is not good at all [at enabling design], and parametrics is particularly bad at that (...) [However] Rhino is very easy to stretch and pull and erase things, and add new things, and is a very fluid thing, but parametrics [like Digital Project] is just awful at that."[291]

This narrative is an expression of a deeply engrained understanding, in our culture, of design as a hands-on, unstructured exploration of physical materials:[292] the degree to which a digital environment is able to *mimic* the manipulation of physical objects in space becomes the key to the system's imagined ability to support "design." In contrast, the mechanistic environment of parametric modeling systems are not "good for design" because it only enables users to manipulate representations in highly structured ways —distant from the metaphorical clay of *Rhinoceros* or physical models.[293]

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[289] Shelden, "Interview with Dennis Shelden."

[290] The first decade of the 21st century saw the appearance of a large number of consultancies focusing on digital design information.

[291] This form of operation contrasts with parametric systems where descriptions are the result of a structured, hierarchical network of geometric elements and constraints. Shelden, "Interview with Dennis Shelden."

[292] The user interaction metaphor of Rhino is. Authors and researchers like [REF, Killian] have discussed design as an "exploration."

[293] The word *modeling* connotes manual work in a way that other words used to refer to computational design work don't —like *simulation*. A discussion between me and scholar Yanni Loukissas on the subject was referred to in Loukissas, *Co-Designers*.

Shelden suggests, however, that parametric systems define a different form of flexibility. This form of design flexibility doesn't stem from digital shapes mimicking the plasticity of physical materials, but from the modeling of geometric and other kinds of constraints made possible by the *structuredness* inherent to computational descriptions.[294] Rather than the "absolute" flexibility of clay, the kind of design flexibility afforded by parametric modeling systems invokes a constrained space of possible variation: a "design space."[295] The notion of a "design space," and the questions about the different ways to imagine its exploration, is nicely captured in the following two excerpts:

"In a parametric modeling system you are not just creating geometry, you are creating space of possibility, so, when you do it well, then it's tremendously powerful because it captures all possible states that you may be interested in, but there's a whole host [of design possibilities] in other states that you don't capture. And I think that every system is like that (...) So I guess that, that question about how the state space evolves, and the limits of a particular state space (...) And "Some of the interesting critical thinking about design it's not just about changing the state of the design, it's about changing the state of the state-space. As far as I know there's nothing out there that can model sort of the bifurcation of state-spaces in a sort of an easy fashion, and I think that's a really fascinating question. The Deleuzian question, which is: How do you capture the topological variance of different state-spaces and then the continuity across those?[296]"

Design is itself a plastic concept. Its contemporary definition is inseparable from and contingent upon the technological systems we use to inscribe it, communicate it, and document it. In the technical practice of organizations like Gehry Technologies, the boundaries of design are constantly enforced and redrawn to explicate different aspects —legal, professional, practical— of practice, illustrating this plasticity.

Conclusions

The software empire

This chapter has discussed key aspects the Building Information Modeling by analyzing the voices of 3 key proponents. Also important, I have shown how, unlike the first commercial systems, the ideas behind BIM closely reflect the design philosophies articulated by the early pioneers in the *Computer Aided Design Project*: a reconfigured discourse of design as a computational, technical practice, premised on the accuracy of structured computational descriptions, and on the centrality and universality of the infrastructures for

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[294] In previous chapters, I have referred to this structuredness as an "algorithmic tectonics."

[295] For an exploration of this theory of design through constraints see: Kilian, "Design Exploration Through Bidirectional Modeling of Constraints."

[296] Shelden, "Interview with Dennis Shelden."

the circulation of digital information. These aspirations, and the techno-cultural imaginaries they set in motion, can be seen as a process of hegemony formation.

Technology is not "up for grabs." As suggested by the exchange between Witt and the student described above, and by the transformative tensions revealed by Shelden's conceptualizations of design technology, *Building Information Modeling*, is premised on a techno-social proposition that de-stabilizes a crucial narrative in architecture about the primacy of design over construction.[297] This de-stabilization has the effect of reducing the professional space of design —traditionally understood as drawing-centered project documentation.

In the remaining three chapters I provide an ethnographic portrait of *Building Information Modeling* from the field. I now turn to critically consider the geographical and political context of these practices, and its participants' use of the tropes of centrality and universality identified above, to make sense of their roles.

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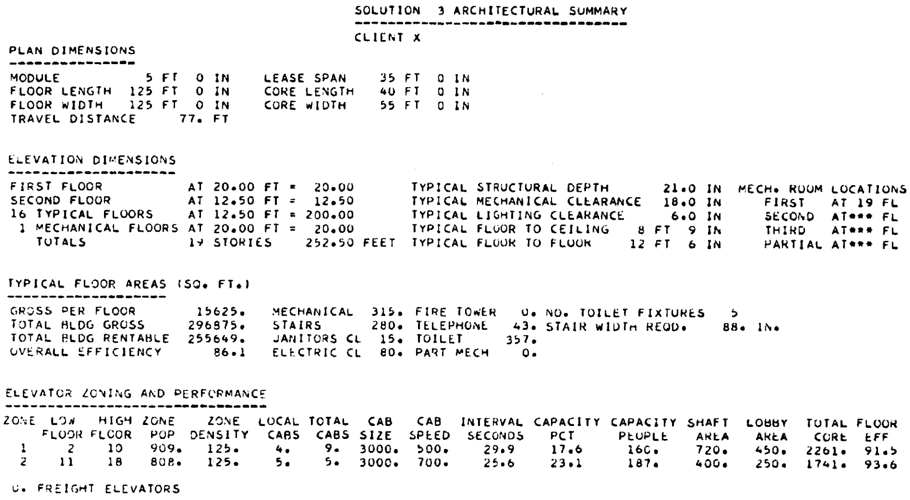
[297] See Chapter 1.



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                                  SOLUTION  3 ARCHITECTURAL SUMMARY
                                  ---------------------------------
                                  CLIENT X
PLAN DIMENSIONS
---------------
MODULE            5 FT  0 IN    LEASE SPAN     35 FT  0 IN
FLOOR LENGTH  125 FT  0 IN    CORE LENGTH    40 FT  0 IN
FLOOR WIDTH   125 FT  0 IN    CORE WIDTH     55 FT  0 IN
TRAVEL DISTANCE      77. FT

ELEVATION DIMENSIONS
--------------------
FIRST FLOOR            AT 20.00 FT =  20.00       TYPICAL STRUCTURAL DEPTH       21.0 IN  MECH. ROOM LOCATIONS
SECOND FLOOR           AT 12.50 FT =  12.50       TYPICAL MECHANICAL CLEARANCE   18.0 IN     FIRST    AT 19 FL
16 TYPICAL FLOORS      AT 12.50 FT = 200.00       TYPICAL LIGHTING CLEARANCE      6.0 IN     SECOND   AT*** FL
 1 MECHANICAL FLOORS   AT 20.00 FT =  20.00       TYPICAL FLOOR TO CEILING     8 FT  9 IN     THIRD    AT*** FL
   TOTALS              19 STORIES    252.50 FEET  TYPICAL FLOOR TO FLOOR      12 FT  6 IN     PARTIAL  AT*** FL

TYPICAL FLOOR AREAS (SQ. FT.)
-----------------
GROSS PER FLOOR        15625.   MECHANICAL  315. FIRE TOWER    0. NO. TOILET FIXTURES   5
TOTAL BLDG GROSS      296875.   STAIRS      280. TELEPHONE    43. STAIR WIDTH REQD.     88. IN.
TOTAL BLDG RENTABLE   255649.   JANITORS CL  15. TOILET      357.
OVERALL EFFICIENCY      86.1    ELECTRIC CL  80. PART MECH     0.

ELEVATOR ZONING AND PERFORMANCE
-------------------------------
ZONE  LOW   HIGH ZONE   ZONE    LOCAL TOTAL  CAB   CAB   INTERVAL CAPACITY CAPACITY SHAFT  LOBBY  TOTAL FLOOR
     FLOOR FLOOR  POP  DENSITY  CABS  CABS  SIZE  SPEED  SECONDS    PCT     PEOPLE  AREA   AREA   CORE  EFF
 1     2    10   909.   125.     4.    9.  3000.  500.    29.9     17.6     160.    720.   450.  2261.  91.5
 2    11    18   808.   125.     5.    5.  3000.  700.    25.6     23.1     187.    400.   250.  1741.  93.6

0. FREIGHT ELEVATORS
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Figure 2—Architectural Summary

Figure 15. **Output of SOM's "Building Optimization Program" circa 1968.**[298]

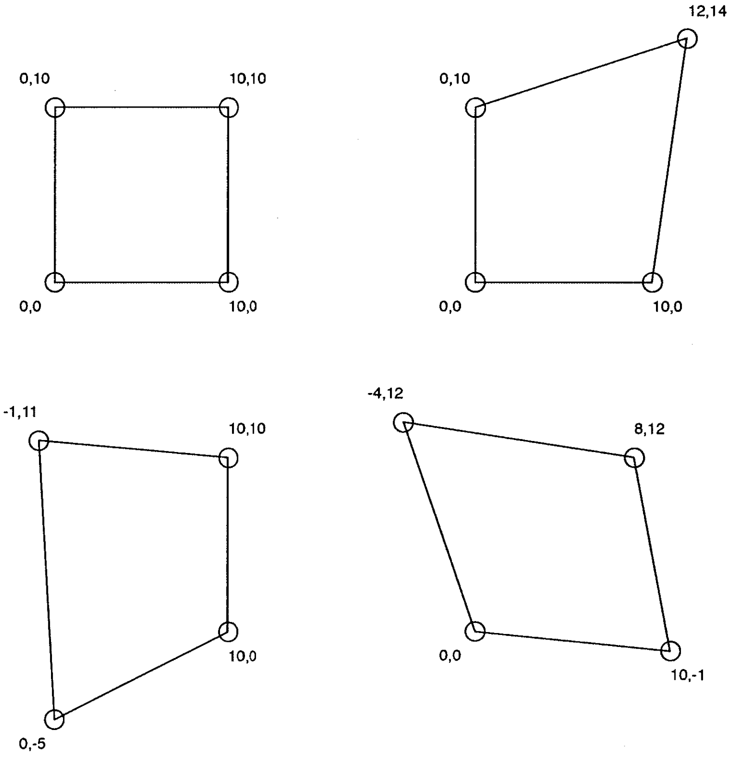

Figure 16. **Illustration of the flexibility of a square defined parametrically.**

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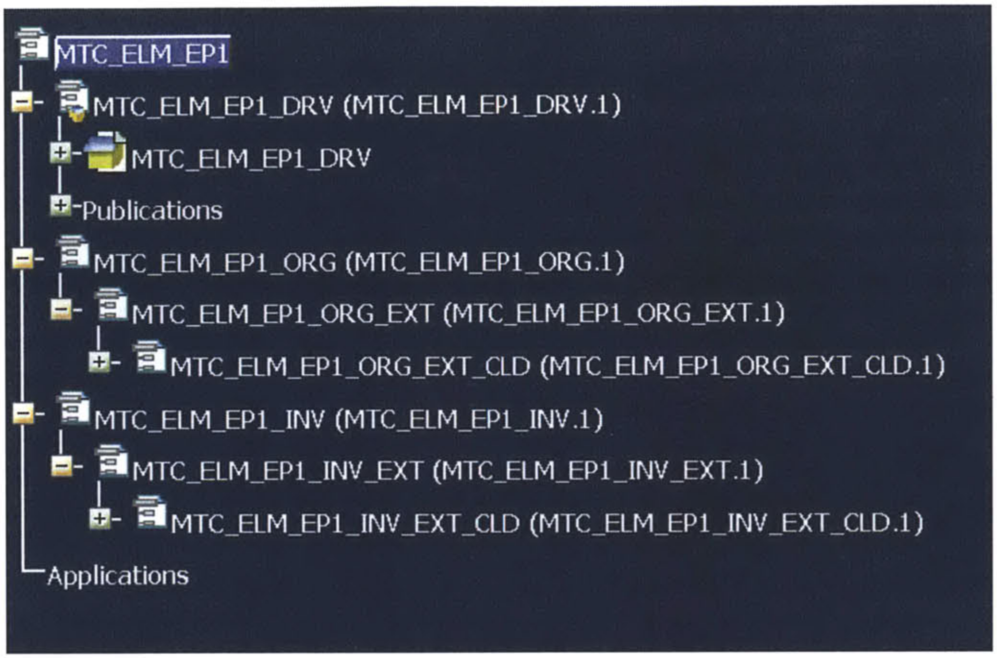
[298] Harper, "BOP: An Approach to Building Optimization."



MTC_ELM_EP1
- MTC_ELM_EP1_DRV (MTC_ELM_EP1_DRV.1)
  - MTC_ELM_EP1_DRV
  - Publications
- MTC_ELM_EP1_ORG (MTC_ELM_EP1_ORG.1)
  - MTC_ELM_EP1_ORG_EXT (MTC_ELM_EP1_ORG_EXT.1)
    - MTC_ELM_EP1_ORG_EXT_CLD (MTC_ELM_EP1_ORG_EXT_CLD.1)
- MTC_ELM_EP1_INV (MTC_ELM_EP1_INV.1)
  - MTC_ELM_EP1_INV_EXT (MTC_ELM_EP1_INV_EXT.1)
    - MTC_ELM_EP1_INV_EXT_CLD (MTC_ELM_EP1_INV_EXT_CLD.1)
- Applications

Figure 17. ***Digital Project's*** **"product tree."**

Figure 18. ***Digital Project's*** **user interface.**

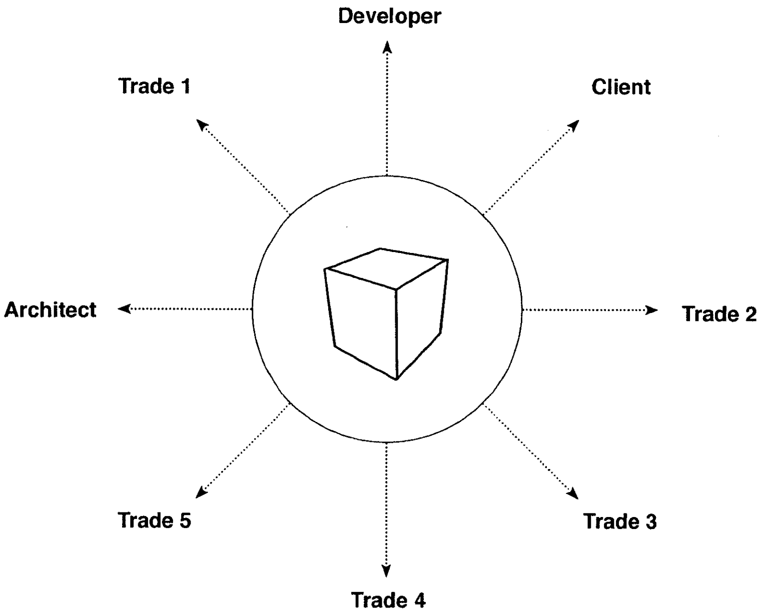


Figure 19. **Reconstruction of commonly used diagrammatic representation of BIM. This kind of centralized representation is conventional to BIM proponents.**

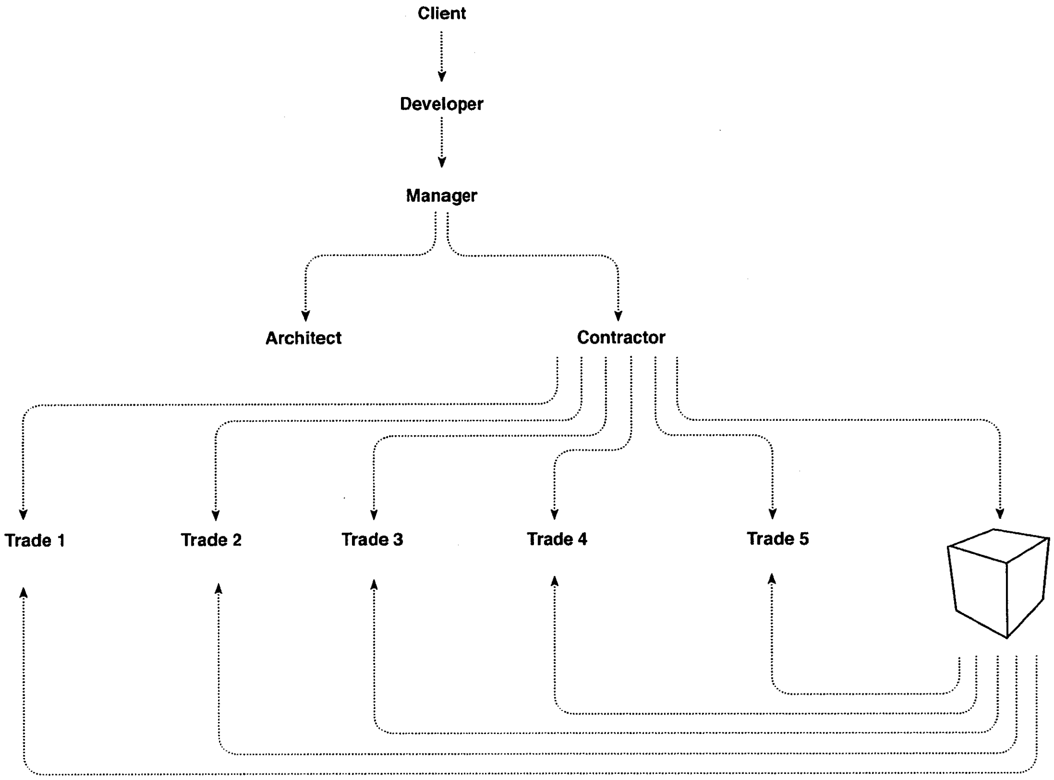
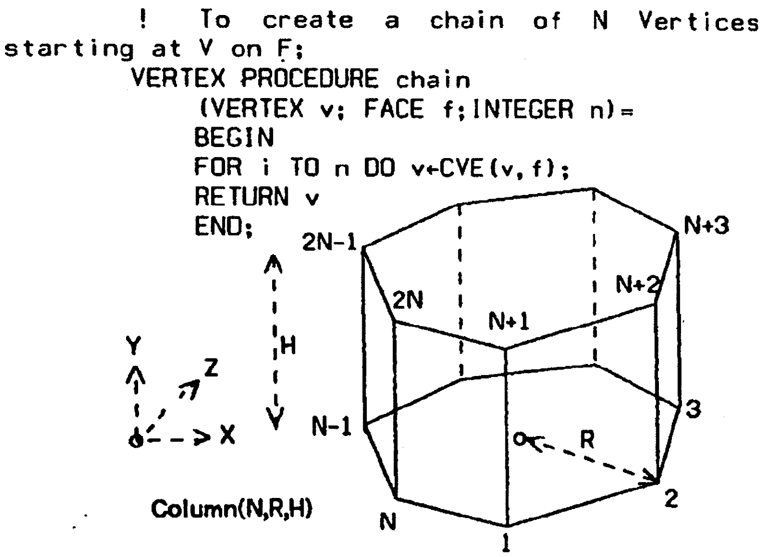
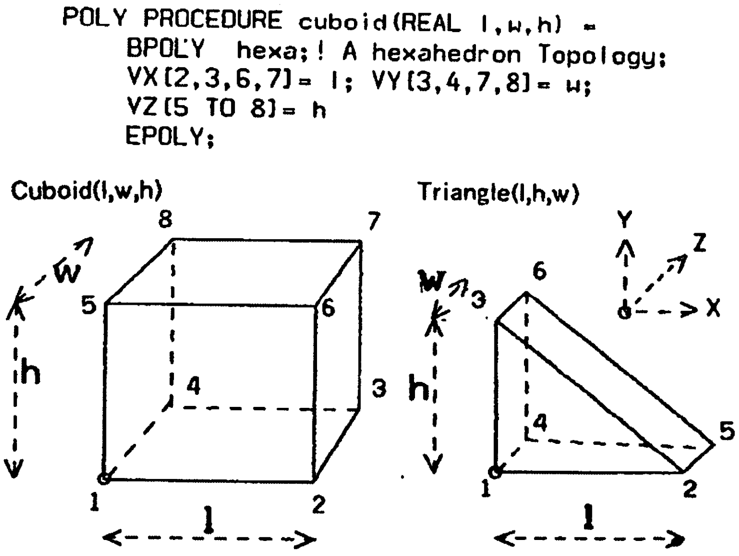


Figure 20. A conventional diagram representing the actors in a project in practice is not central, but hierarchical. The BIM is represented by a box.



```
        !   To  create  a  chain  of  N  Vertices
starting at V on F;
      VERTEX PROCEDURE chain
          (VERTEX v; FACE f;INTEGER n)=
          BEGIN
          FOR i TO n DO v←CVE(v,f);
          RETURN v
          END;
```

Figure 21. **Image from Eastman's project GLIDE.**[299]



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POLY PROCEDURE cuboid(REAL l,w,h) =
     BPOLY  hexa;! A hexahedron Topology;
     VX[2,3,6,7]= l; VY[3,4,7,8]= w;
     VZ[5 TO 8]= h
     EPOLY;
```

Figure 22. **Image from Eastman's project GLIDE.**[300]

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[299] Eastman and Henrion, "Glide."

[300] Ibid.

5. BUILDERS OF THE VISION

Introduction

The social worlds of *Building Information Modeling* I observed exist within the larger contexts of the City and Emirate of Abu Dhabi, the United Arab Emirates (UAE), and the Middle East [See Figure 23]. The geographical, political and social specificity of these contexts is crucial to the subjects of this study — mostly expatriates from Europe and the region—, their everyday lives, the projects they develop, and the institutional arrangements within which they operate.[301] Moreover, within these broader contexts, the socio-technical practice of BIM is embedded in an evolving culture of architecture production characterized by increasingly large and flexible transnational networks of work enabled by technological shifts in information technology and travel. Modern self-representations of the State in Abu Dhabi, visible in advertisements, newspapers and public exhibitions, seek to fashion the emirate's capital as a global metropolis and as a hub of business and culture [Figure 24]. This imagined modernity is figured, as anthropologist Ahmed Kanna has pointed out, as a white European upper class utopia [Figure 25].[302]

Representations of ambitiously iconic architectural projects designed by the world's most famous practitioners perform symbolically beyond their architectural function as illustrations of the State's grandiose vision for the city. Projects bearing the signature of a "starchitect"[303] are elements of a strategy aimed at giving the city a competitive advantage in a global struggle for the interconnected features of media attention, tourism and investment of capital.[304]

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[301] See Magali Larson on Autonomy and heteronomy. Larson, *Behind the Postmodern Facade*, 12.

[302] The emphasis on Europe as an identity model in the UAE can be traced historically—it contrasts with a documented pre-oil identification of the Gulf States with a Pan-Arab ethnical and cultural identity. Kanna, *Dubai, the City as Corporation*, 24.

[303] Popular media has adopted the term "starchitects" to refer to a handful of architects who have have acquired international fame beyond their profession by practicing globally on high-profile institutional commissions. The term is generally considered pejorative by these practitioners, as it portrays them as popular celebrities, rather than as rigorous professionals. See for instance "Frank Gehry: 'Don't Call Me a Starchitect' - Architecture - Arts & Entertainment - The Independent," *The Independent*, December 17, 2009, http://www.independent.co.uk/arts-entertainment/architecture/frank-gehry-dont-call-me-a-starchitect-1842870.html.

[304] Kanna calls this "urban entrepeneuralism" in the context of "place wars." See Kanna, *Dubai, the City as Corporation*, 80.

In this chapter I will seek to illustrate how the socio-technical practice of BIM and the socio-geo-political landscapes of Abu Dhabi are related. To delineate the larger socio-political context of Abu Dhabi, and the place of architecture in it, I will borrow elements from Ahmed Kanna's[305] urban anthropology, and from the histories of the UAE by Chrisopher Davidson[306] and Frauke Heard-Bey,[307] as well as from some recent works in the social sciences that have approached critically the effects of globalization in architectural practice —in particular McNeill[308] and Ghirardo.[309] I use the work of these scholars to set an interpretive framework for my observation of *Building Information Modeling* practice in two projects in Abu Dhabi.[310] In this chapter I critically examine the ability of cultural-imperialist critiques to explain the contemporary technological production of the built environment.

A visit to the mall

Depaysement

> Abu Dhabi, by far the largest State [of the UAE], occupying approximately 87 per cent of the total UAE territory, owes its character to the desert[311].
>
> The capital of Abu Dhabi, bearing the same name as the State, is also located on an island, which is connected to the mainland by two road bridges. The triangular island has about 10 kilometers of waterfront and ex tends for 16 kilometers towards the mainland between lagoons and other islands. It accommodates at present most of the capital's administrative and residential buildings, including the international gallery complex.[312]

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[305] Kanna, *Dubai, the City as Corporation.*

[306] Christopher M. Davidson, *The United Arab Emirates: A Study In Survival* (Lynne Rienner Publishers, 2005).

[307] Heard-Bey, *From Trucial States to United Arab Emirates*, -.

[308] Donald McNeill, *The Global Architect: Firms, Fame and Urban Form* (T & F Books US, 2009).

[309] Ghirardo, *Out of Site.*

[310] Besides a scholarly tradition of urban studies that seek to understand the links between cities' form and the life of communities in its political dimension (see for instance J. Jacobs, W.H. Whyte), Kanna and McNeill's arguments can relate also to previous theorizations of the politics of technology. For instance, scholars like Langdon Winner, Lucy Suchman and Bruno Latour have sought to unpack the political dimension of technology and artifacts (non-humans) by virtue of the way in which their design shapes "possibilities of action." See Lucy Suchman, *Human-Machine Reconfigurations: Plans and Situated Actions*, 2nd ed. (Cambridge University Press, 2006). Langdon Winner, "Do artifacts have politics?," in *The whale and the reactor: a search for limits in an age of high technology* (Chicago: University Of Chicago Press, 1986), 19–39.

[311] Heard-Bey, *From Trucial States to United Arab Emirates.*

[312] Ibid., 12. In p. 171 Heard-Bey mentions that Abu Dhabi is "Place (or father of) the white gazelle.

Driving through the city of Abu Dhabi's Corniche can be a cinematic experience. The long stretch of skyscrapers of the metropolitan downtown area of Al Khalidiya, and the clear blue water of the Arabic seaside make for a pleasant drive along the carefully landscaped, palm-lined highway. Westwards, close to the Emirates Palace —a former royal residence turned a "7 star" hotel with a world-famous gold-vending machine— a monumental sign with a photograph of Sheikh Zayed bin Sultan Al Nahyan with the legend "Our Father Zayed" invites the drivers—and the few pedestrians— to celebrate the deeds of the country's founder: "our father." Just a few minutes away, across an artificial peninsula folding itself North as a hook overlooking the city, is the Marina Mall, an American-style commercial enclave surrounded by a lake of parking lots and (to the east) a Marina docking several hundred modern yachts. After parking my cheap rented Toyota (there's no subway or comprehensive bus-system in Abu Dhabi) I made my way under the lines of white tents shading the cars to the mall's entrance. As I walk through the neutral streets of the mall towards the Carrefour supermarket I pass by other shoppers, most of them expatriates who, perhaps like myself, feel "re-countrified" by the carefully crafted familiarity of the commercial landscape (IKEA, Fuddruckers, a Multiplex —also Chanel, Dior and Armani boutiques) and by the circular predictability of the building's layout. Most of the people I walk by look like members of a Western and, to a lesser extent, South Asian middle class. Some are local, distinguishable by their long clothes,[313] walking separately in gendered groups.

Assisted automation

In order to use a grocery cart in Carrefour, customers have to insert 1 dirham (approximately 1 US quarter) in a coin slot located in the cart's handling bar. I learn from a sticker placed on the green plastic of the cart's handle that the coin will be returned once the cart is placed back in the mechanic cart line located close to the Mall's entrance. After doing my shopping and putting the grocery bags in the trunk of the car I automatically start taking the cart back to the mechanic line (so I can reclaim my dirham), but I am gently stopped by a smiling young South Asian man who indicates, with gestures, that *he* will return the cart to the machine. I then realized that no customer returned the cart by herself to the line, and that South Asian boys, distributed around the lot in a quiet swarm, had formed an informal economic entanglement in the mall as the machine's assistants, or grooms.[314]

Like the space of the Mall, the Emirate of Abu Dhabi represents itself to outsiders as a familiar domain where space articulation and architecture play both symbolic and functional roles. A reductive analogy

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[313] Kandura (male cloak) and Abaya (female gown).

[314] Parking lot ticket dispensing machines also have human grooms. Assisted automation? REFER to Latour's groom.

can be drawn between mall and the State, that illustrates UAE's aspirations to define its own brand of modernity premised on the metaphoric notion of a "bridge" between the Arab and Western worlds, and between "tradition" and "future."[315] However, while the expatriates navigating the familiar space of the mall can be thought of as "flexible citizens," defined by Aihwa Ong as individuals taking advantage of "the split between state-imposed identity and personal identity caused by political upheavals, migration, and changing global markets,"[316] the boys in the parking lot are part of a different, less "flexible" reality which complicates the intended progressiveness of the State's vision, and the technological and social scaffoldings that are deployed for the production of its built environments.

Abu Dhabi

A fatherly state

Without delving too deeply in UAE's fascinating and complex history of colonialism, tribal rule, and the current family-state, it's important to note the way in which the wealth derived from the oil findings in the 1970s enabled ruling dynastic elites—the Maktoums (Dubai) and the Al Nayhans (Abu Dhabi[317])— to consolidate their absolute mandate over the country through what is conventionally known as the "ruling bargain." Scholars commonly understand such bargain as a direct exchange of welfare benefits and valuables (housing, education, large forgivable loans), for the political demobilization of critical voices — typically from a merchant class— that brought the rulers' mandate into question.[318] Historian of the UAE Christopher Davidson, for instance, explains the "ruling bargain" in Abu Dhabi as a transformation of resources into (absolute) political power: if Abu Dhabi's Sheik Zayed bin Sultan Al-Nahyan "could oversee the efficient distribution of wealth to [indigenous] families and individuals, and not just spend on large scale development projects, then the sheikhdom's lucrative natural resources could be effectively transmuted into his own personal generosity, thereby rendering the population eternally grateful for his munificence.[319]" The effect of the consolidation of the Sheik's mandate was thus not so much a bargain but the success of an ethno-nationalist, authoritarian and anti-reformist project of state-building. Crucial tenets of this project were, on one hand, paternalistic oil-funded policies designed to de-incentivize

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[315] See a discussion about Abu Dhabi's iconic enactments of energetic futures in: Gokce Gunel, "Preparing for an Oil-less future: Energy, Climate Change and Green Business in Abu Dhabi" (Ph.D., Cornell, 2012).
[316] Aihwa Ong, *Flexible Citizenship: The Cultural Logics of Transnationality* (Duke University Press Books, 1999), 3.
[317] These elites originally fashioned by British imperialism to simplify its control over trading and strategic interests.
[318] Kanna writes that "Oil and the ruling bargain certainly expanded the material welfare of Emiratis, but the discourses of many Emiratis suggested a constriction of political horizons.Kanna, *Dubai, the City as Corporation*, 25.
[319] Davidson, *The United Arab Emirates*, 52.

political engagement; and on the other, a representational politics of the state geared towards construing itself as a fatherly benefactor protecting its citizens (and foreigners of a certain class and racial background). The boundaries of this welfare state are thus strongly tied to a notion of citizenship based on hereditary ethnic privilege.[320]

Perfect (South-Asian) slaves

Up until the 1960s the local population in the Gulf countries was heavily involved in the harsh labors associated with oil production. In the 1970s, with the independence from the British, the UAE started to bring temporary migrant workers in large numbers to do the hard labors of the construction and oil industries. With the benefits of the oil economy, the Emirati local population went to occupy managerial and government positions, and their participation in the construction workforce (as well as in all primary and service sectors of the economy) decreased to an almost negligible percentage. They were replaced, first, by Middle Eastern workers coming from Lebanon, Egypt, and, more recently, by South Asian workers from India, Pakistan and Bangladesh.[321] These workers now face conditions which, according to political scientist Adam Hanieh "you can't describe by anything more than a very severe exploitation resembling in many cases forms of slavery…" Hanieh goes on to point out a crucial contrast between the realities of labor and Abu Dhabi's architectural exuberance: "These projects, these fanciful projects, are built on the back of construction workers that face very severe kinds of exploitation."[322] As Kanna reminds us, these "cities do not 'emerge from the sand overnight' without huge, expendable armies of workers lacking any claim to protection from the state."[323] In a series of reports Human Rights Watch has kept pressure on the UAE government to oversee more closely the companies hiring migrant workers. The most recent report, from March 2012, documents how despite certain improvements in labor conditions for migrants many remain unprotected. The abuses by the employers reported by HRW include misinforming the workers about the terms of the contract, "indebtedness of recruitment fees paid to obtain their jobs in the UAE … illegal salary deductions, in some instances overcrowded and

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[320] Not unlike European countries like (to my knowledge) Switzerland and Germany.

[321] According to the (conservative) estimate of the U.S. Department of State, migrants from India, Pakistan and Bangladesh amount to 40% of the total population of the country. U.S. Department of State Bureau of Near Eastern Affairs, "United Arab Emirates," *U.S. Department of State*, December 29, 2011, http://www.state.gov/r/pa/ei/bgn/5444.htm. It's important to note that South Asian labor is not, however, homogeneously devoted to hard labors and an increasingly number of South Asian "flexible citizens" occupy consultant and engineering positions. Neha Vora's anthropological work cited in Kanna: "middle class Dubai South Asians enact two simultaneous and contrasting identities, as global neoliberal participants in a free-market economy and as a disenfranchised racial group." Kanna, *Dubai, the City as Corporation*, 36.

[322] Adam Hanieh, "Modern Slavery in Gulf Countries," Video (youtube), May 14, 2011, http://www.youtube.com/watch?feature=player_embedded&v=4D_O3tU3Vss.

[323] Kanna, *Dubai, the City as Corporation*, 27.

unhygienic housing conditions"[324] and, disturbingly, the custody of the worker's passport by their employers, therefore impeding the worker's freedom of movement [Figures 26 and 27].[325] The voices of the migrants are not audible in the HRW reports or in the media.[326] These conditions have been noted by other pressure groups and independent bodies, including a New York based group of more than 130 artists, curators and writers who in 2011 started a boycott of the Abu Dhabi Guggenheim by collectively refusing to participate in any of the museum's activities until conditions for migrant workers were radically improved. A statement posted in their website succinctly asserted that

> Artists should not be asked to exhibit their work in buildings built on the backs of exploited workers. Those working with bricks and mortar deserve the same kind of respect as those working with cameras and brushes.[327]

The Mall-scape

While in the Mall-scapes and gated communities of Abu Dhabi the reality of segregation is only tangentially visible in the formal and informal economies of service, in the construction sites I frequented during my fieldwork[328] I was able to witness aspects of the heavy restrictions to which members of the work force were subjected: workers' movements were constrained by their inability to get driver's licenses, the inaccessibility of public transport, the meager salaries, and the different hiring company's frequent confiscation of their passports. As a result of the above most laborers rarely visit places different from their labor camp and the construction site. Long lines of workers lining up to board the company's bus were a

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[324] Two Human Rights Watch reports focus on the issue: Human Rights Watch, *"The Island of Happiness:" Exploitation of Migrant Workers on Saadiyat Island, Abu Dhabi*, May 2009, www.hrw.org/sites/default/files/reports/uae0509webwcover_4.*PDF*. And Human Rights Watch, *The Island of Happiness Revisited: A Progress Report on Institutional Commitments to Address the Abuses of Migrant Workers on Abu Dhabi's Saadiyat Island*, March 2012, http://www.hrw.org/reports/2012/03/21/island-happiness-revisited.

[325] The tolerance of local authorities with these practices may derive from a historical reliance of Emirati economy on slave labor. Despite British colonists' opposition to slave trade, the commerce of pearl and domestic slaves from Baluchistan (Pakistan), Persia (Iran) and Africa, was common until the late 1930s. It was the changing economic conditions—the decline of the pearl economy and not humanitarian concerns—what, according to Frauke Heard-Bey, officially ended the slave traffic in the 20th century. In her 1982 book "From Trucial States to United Arab Emirates" Heard-Bey provides an unparalleled picture of the country's history. It is worth noting, however, that in her treatment of the issue of slavery she abides by the still common today trope that despite the harsh conditions they are sometimes subjected to, slaves are, in relative terms, better as slaves than in their countries of origin.

[326] A recent literary exception is the novel by Indian authors Benyamin & Joseph Koyippally (Tr.), *Goat Days* (Penguin Books, 2012).

[327] Human Rights Watch, "UAE: Artists Boycott Guggenheim-Abu Dhabi: Protesting Exploitation of Foreign Migrant Workers", n.d., http://www.hrw.org/news/2011/03/17/uae-artists-boycott-guggenheim-abu-dhabi.

[328] And from my very privileged role as a consultant.

common sight at the end of every workday. The deserted highways temporarily crowded by lines of small buses occupied by invariably male[329] passengers, taking them back to their cities behind fences.[330]

The aspired modernity of the State is thus problematic, at least, from the standpoint of the conventional ideals of Western democracy. The alluring urban visions of the UAE —as well as its status as tax-free consumerist paradise— coexist with and are made possible by the explicit exclusion of racial and economic groups from the benefits awarded to "flexible citizens." The nature of this exclusion can in many cases amount to systematic exploitation and —according to critics like Hanieh— slavery. Critics of this arrangement consider it ironic that the UAE's shiny infrastructure, predicated on the notions of modernity, progressiveness and (more recently) sustainability[331] is effectively being built by an underclass of people whose rights are severely restricted compared to those of the locals and privileged foreigners. The following passage on Dubai can also describe Abu Dhabi.

> … its immense enclaves and daring buildings seem to represent a progressive vision and futuristic orientation for the city (…) but New Dubai is, I argue, a typical urbanist project, governed by an exclusionary, ethnocratic logic that in fact strongly resonates with conservative discourses. The irony is that urbanists such as starchitects see themselves as global actors, generally unencumbered by local baggage. In reality (…) the more recent examples of architectural whimsy, resonate with and reinforce local hegemonies and structures of racial and class exclusion[332].

Following on Kanna's notion of the post-industrial capitalist city as a site of "symbolic processes of culture and political processes of hegemony," and as a scenario of "labor flexibility, capital mobility, a crisis of profit accumulation and a consequent retrenchment of elite economic interests," Abu Dhabi and Dubai's politics not only manifests in the abstract legal frameworks that regiment labor and define the boundaries of citizenship, but also through the city's physical form and architecture.[333] The labor camps where migrant workers live are away from the city centers and out of sight from the *Mall-scape.*[334] The

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[329] By 2010 the population of the UAE was 70% male. Rem Koolhaas et al., *Volume 23: Al Manakh Gulf Continued*, ed. AMO et al. (Archis, 2010).

[330] For a review of spatial segregation in the US see

[331] A recent anthropology dissertation by Gokce Gunel interrogates the constitution of an imaginary of Emirati progress and iconicity associated with energy sustainability and green business. See: Gunel, "Preparing for an Oil-less future: Energy, Climate Change and Green Business in Abu Dhabi."

[332] Kanna, *Dubai, the City as Corporation*, 38.

[333] It's important to note that, as Kanna reminds us, there is a danger in conceiving of these spatial manifestations of power as prescriptive of human relations. Citizens and expatriates use cities, much as in literary theory, to reconstruct meanings of their own through interpretation, conceiving urban space as an open-ended field of urban and human relations. Kanna adapts this notion of open-endedness from literary-theory to spatial analysis. In particular conceptions of interpretation and analysis of work in Erdreich and Rappaport.

[334] With this term I refer to the spatial complexes of malls, gated communities, and other expatriate enclaves.

laborers, who are not allowed driving licenses[335], are thus effectively segregated from large portions of the city's life. Or rather, Abu Dhabi's urban life is fragmentary, composed of radically different kinds of experience. Such is the tangible urban expression of the "ruling bargain.[336]"

I have taken a critical look at the city of Abu Dhabi beyond its self-representation as a modern and progressive metropolis, and looked at aspects of its urban form as disclosures and enactments of power relations, as part of Abu Dhabi's —to use Kanna's term— "representational politics[337]." With this, I have sketched the larger social and urban context in which the technological practices of architectural production I observed are inscribed. In the following section I will adopt an architectural perspective through my subjects and other sources of ethnographic insight to interrogate the architect's confrontation with Abu Dhabi's particular social and political context —as a way to understand this particular world of practice.

The architects' bargain

Beautiful things

> (...) the UAE is a quite an amazing place because you work with all the different nationalities from all over the world and you build amazing structures. It's a dream for an architect and for an engineer to be able to work here because there are budgets available that allow you to build things that are quite amazing.

The quote is an excerpt from an interview with Bernd Lutz,[338] a tall German architect and engineer in his early forties. Despite being trained both as an architect and engineer Bernd preferred the intensity of construction sites to the relative calm of a designer's desk. Six years ago he started working for the German construction giant QUATRO and started traveling for work in North Africa and South Asia. Two years ago he moved to Abu Dhabi to manage the construction of the Abu Dhabi branch of the

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[335] In order to be eligible for a driving license residents of the UAE must provide proof (copy of contract and letter from employer) that they occupy a position as "directors" or "managers" in their companies. See official UAE driving regulations in http://www.abudhabi.ae/egovPoolPortal_WAR/appmanager/ADeGP/Citizen?_nfpb=true&_pageLabel=p_citizen_departments&did=16804&lang=en

[336] Moreover, it seems apparent that the regional civil unrest termed by the media as the "Arab Spring" showed local rulers that social tensions can turn messy; In May 2012 it became public that the UAE had hired an American company, a derivation of Blackwater, to build a mercenary army "intended to conduct special operations missions inside and outside the country, defend oil pipelines and skyscrapers from terrorist attacks and put down internal revolts." Mark Mazzetti and Emily Hager, "Blackwater Founder Forms Secret Army for Arab State - NYTimes.com", n.d., http://www.nytimes.com/2011/05/15/world/middleeast/15prince.html?hp.

[337] See Kanna, *Dubai, the City as Corporation*, 17.

[338] A pseudonym is used to protect the anonymity of the subject.

British Thomas Wynne Mall—one of the many big-name franchise projects planned for the city (yet one of the few actually under construction). His description of the UAE as an architect's "dream" is illustrative of a common sentiment among members of the design and construction communities, who see the oil-rich Emirate as a mecca of contemporary practice because of large budgets, big paychecks, and the opportunity to work on "amazing projects." In the following excerpt Bernd explains how the country's wealth supports "beauty" in architecture and "prowess" in engineering.

> I think, as an architect in this part of the world, compared to back home, back home the labor is more expensive than the materials, here the materials are more expensive than the labor. So, there are big budgets for materials. So if you want and if you like gold plated ceilings or if you like nice marbles or if you like mother of pearl tiles or… there are budgets for these kinds of finishes here, and it is amazing to build beautiful things! And to build beautiful things the budget needs to be there, and it is here. So that as an architect. As an engineer, OK the examples are there, the Burj Dubai, the tallest structure of the world…

For Bernd, the fact that in Abu Dhabi labor is cheaper than materials is not problematic. It is in fact regarded as an welcome circumstance affording architects and engineers the freedom to make propositions that wouldn't be feasible in other parts of the world. Two aspects of Bernd's statement are important for our purposes: First, it illustrates the architectural side of the "ruling bargain:" by sponsoring creative freedom the UAE regime is able to attract what Deyan Sudjic calls —wittingly but hyperbolically— the "flying circus of the perpetually jet-lagged"[339] elite of architectural stardom. As before in UAE's (and in fact, global capitalist) history, financial conditions pave ways for eased consciences. The second aspect to note, the transparency with which he acknowledges a classic professional delimitation between the fields of architecture and engineering. In his account the architects are concerned with finishes and surfaces —the beautiful, while engineers are concerned with structures— the firm. Moreover, Bernd construes Abu Dhabi as a temporary place of moral and cultural self-improvement.

Multi-culturalism as managerial advantage

> Everybody who works here is here to better themselves in a certain way and they are here, I think most of the people, or all of the people, are here, to work here for a certain period and then go back to wherever they come from. So that gives a certain dynamism to this place that the people who come here are here to work. And they're here to work hard, and they want to do their best, and then go.

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[339] In his book "The Edifice Complex" Sudjic narrates the architect's historical dependence on power (often an authoritarian state), as a manifestation of "power, glory, and spectacle." See Sudjic, *The Edifice Complex*, 317.

> So uhm, in that way, for me as a project manager it is easier to work than for instance working in Libya or in Egypt, because you're working with people who are willing to work and who want to work. In other countries you work with local people who are sometimes, first of all, they are in their country and you are the foreigner and is sometimes more difficult to be in a position of authority when you are working with other people.

Bernd finds it easier to exert his professional authority in a culturally diverse team than in more homogenous environments with more established conventions of professional practice. However, not everyone shares his view on the managerial advantage of multi-culturalism. BJ[340] is a 30-year-old architect from China who works as a design and construction coordinator in the Mall for a French consultancy firm using BIM. She got her architectural education and first professional experiences in Australia. In contrast with Bernd, BJ (who has to work with a very diverse group of subcontractors on a daily basis) feels that the cultural diversity makes her BIM design coordination work more difficult because of the different languages, and cultures of representation and work.

> So I think this is the reality of this project ... this place is very complex because... Maybe you have to understand Hindi! I don't know, or the Indian construction culture to, to, if you want to engage the construction process. Because there's so many different... What I talk about understanding the cultures is that, coming from Australia, it's a very insular kind of industry, so people will understand each other. The builders understand the architects, there's understanding ... because they've been working together and they only work with each other! There's no external laborers, or external... expats [clear reference to the UAE context], it's mainly just a very pure Australian society, which allows you to have kind of an innate understanding of [how] the process works, but elsewhere it's more challenging to get.

Her frustration transfers to her use of BIM as a tool for coordination. In the following excerpt she notes the varied responses to technology in her coordination work.

> There are so many different kinds of people in this project, different backgrounds, different ways of working, different personalities, and um, some people really want to work with BIM, some people don't, or appropriate it for their own means, they use it when they want it and ignore it when they don't but you can't do that, yes, if you ignore it you cannot get of it what you need. So, um, I don't know if it would be different if I had worked in a more mono-cultural environment.

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[340] A pseudonym is used to protect the anonymity of the subject.

Despite the fact that the working conditions of the migrant laborers were hard to miss, mobile consultants like BJ and Bernd generally avoid discussing them. Bernd, in fact, sees the availability of extremely cheap labor as positive, and highlights the effect of this economy on the affordability of materials for creating "beauty" and "amazement." Notably, Bernd represents the existing income and cultural differences as *managerial advantages.*[341] In contrast, for BJ, cultural differences were a managerial problem because of the difficulties to communication during BIM coordination. That's why, in her work as a coordinator, she conceived of BIM as a "common language" for design and construction—even superseding the natural languages of the members.[342] Bernd and BJ are "flexible citizens,"[343] skilled professionals moving across national boundaries through networks of corporate practice and towards hubs of capital flow. Clearly apart from the laborers, they belong[344] to a group of expatriates who benefit from the "rush" of qualified professionals ushered by Abu Dhabi's well-funded drive towards the construction of iconic projects seeking to put the city "on the map."

Importing the Bilbao effect

The city of Abu Dhabi exemplifies a global era in which architectural iconicity is understood as a trigger of economic development. Magali Larson, for instance, discusses the politics of urban investment and real-state boom of the 1970s and early 1980s in the US that spurred a competition between cities and the rise of architecture as a gentrifying agent in American society.[345] However, in its contemporary form, the search for iconicity features a distinctive set of characteristics: the dominance of architectural representations in digital media, the globally competitive "place wars" for tourism and investment of capital, and the status of the architect as an all-year round traveler and international media-celebrity. The emergence of this kind of "urban-entrepreneurship" is commonly traced to The Guggenheim Museum in Bilbao, Spain —designed by Frank Gehry and finished in 1997. This building is credited for having attracted flows of tourism and money that rescued the deindustrialized[346] Basque Country city from

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[341] There are different attitudes towards authoritarianism. Alain Raynaud is a French architect who works as a "task-force" manager in the construction of the Thomas Wynne Mall. As his contract comes to an end he was seeking for a job. He eventually declined an offer to work for the president of Congo because he was worried how "that would look in his CV" once he returned to France because of the regime's HR reputation. This shows how, for Raynaud, the UAE has been successful in maintaining a public image of relative modernity despite the criticisms.

[342] This ambition, of BIM as a "common language," and the subsidiary notion of the projects in the Middle East as "Babel Towers" is frequently echoed by members of the BIM consultancies. Also, by international standards consortia. It is in fact one of BIM's main tenets. I will explore this in more detail in the next chapter.

[343] Ong, *Flexible Citizenship.*

[344] As I myself belonged for a period of one year.

[345] See Larson, *Behind the Postmodern Facade*, 80.

[346] "The term *deindustrialization* suggests the effect of different movements of capital in search of higher profits. It refers to the 'runaway shop' phenomenon—the decision by industrial firms to leave the nation's more mature

economic decay. The building inaugurated an era, roughly spanning the decade between its construction in 1997 and the economic crisis of 2007, during which iconic projects were conceived as triggers of urban development and key commodities for cities aspiring to a global "brand." By virtue of an exceptional design that puts a city "on the map," the logic goes, tourism activates the local economy and rescues a city from decay. This phenomenon, which involves city governments, ambitious plans for cultural infrastructures, and "starchitects," has become known, to Gehry's irritation, as the "Bilbao Effect." In an interview with David Sheff for Playboy, Frank Gehry discusses the "Bilbao Effect" and speaks suggestively of architecture's role in society.

> It's not new. The Bilbao effect is the Parthenon effect. The Chartres Cathedral effect. The Notre Dame effect. The press labeled it The Bilbao effect, I didn't name it. It's nothing new that architecture can profoundly affect a place, sometimes transform it. It's like architecture and any art can transform a person, even save someone. It can for children – for anyone. It still does for me.[347]

McNeill suggests that "the power of the icon as architectural discourse is reliant on the intensified circulation of visual images, combined with an embodied, performed set of tourist practices on the part of architects and their professional critics and journalists."[348] The architectural object becomes, even before its construction into a powerful vehicle of an urbanist vision (in the Kanna/Lefebvre sense) through the widely circulated images with which it is promoted.[349] Current web-based social networking and telecommunications intensify the speed and effectiveness of these transactions.[350]

While many cities have sought the "Bilbao Effect," perhaps no city illustrates the faith of a local elite in its benefits better than Abu Dhabi —where billions of dollars are invested in ambitious urban utopian visions, and the world's most famous architects have been summoned to design it. The scale of interventions planned for the Emirate is in fact striking. Saadiyat Island, located 10 miles to the East of Abu Dhabi's center, is the site of an ambitious urban development project depending on the Abu Dhabi Tourism Authority (ADTA), through the Tourism Development Investment Company (TDIC) [See Figure 28]. The plan comprises an assortment of "starchitectural" works including a culture district with a branch of the Guggenheim Museum designed by Gehry Partners, a branch of the Louvre museum designed by Ateliers Jean Nouvel, a Performing Arts Center designed by Zaha Hadid, the Sheik Zayed National Museum designed by Foster and Partners, and a New York University Campus, designed by

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industrial regions for domestic or foreign areas that offer cheaper facilities, cheaper labor, lower unionization rates, and more complacent local governments." See Ibid., 68.

[347] Sheff, "Interview: Frank Gehry."

[348] McNeill, *The Global Architect.*

[349] Of the urbanist broadly understood as a cultural entrepreneur.

[350] For a critical discussion on the "Bilbao Effect" see McNeill, *The Global Architect.*

Rafael Viñoly. Outside the tiny island other projects constituting the global vision include Al Raha Beach, the Central Market (Designed by Norman Foster's office), the Yas Island touristic complex, comprising a Formula One Circuit and a hotel designed by Asymptote, a Ferrari Theme Park designed by Benoy, the Thomas Wynne Mall Abu Dhabi designed by AEDAS, and Masdar City, an ambitious green-building urban project master-planned by Foster and Partners [Figure 29].[351] The construction of these other projects is overseen by Aldar properties, an organ that depends (like most of Abu Dhabi's construction) on a centralized structure of funding that is ultimately controlled by Abu Dhabi's crown prince H.H. General Sheikh Mohammed bin Zayed Al Nahyan. Through the construction of these "starchitect" projects the Emirate's rulers seek to build Abu Dhabi into a sophisticated global metropolis.[352] However, the ambitious vision seems still distant from reality. Many of the wide highways of Yas and Saadiyat Islands remain empty —mostly inhabited by camera radars that keep the few driver's speeds in check (an illustration of the country's heavy policing on its inhabitants)— connecting a still sparse network of hotels, touristic attractions and gated residential communities for expatriates and locals. Only a few of the projects listed above are built, and most of the iconic ones —including the museums— are un-built, delayed or indefinitely suspended.[353] The monumental road infrastructure is in place, awaiting an uncertain future demand. While the immense oil-wealth of Abu Dhabi shielded it from the devastating effects the 2007 global financial meltdown had in the neighboring emirate of Dubai,[354] the investment pace slowed significantly. At the time of my fieldwork pushed deadlines, delayed contracts, and an atmosphere of uncertainty loomed over the project teams.

Conclusion

Self-expression and (non) politics

In this chapter I have presented aspects of the geographical, social and political contexts of architectural production in the UAE and reflected on the ways in which actors involved confront them. To do this I

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[351] See Gunel, "Preparing for an Oil-less future: Energy, Climate Change and Green Business in Abu Dhabi."

[352] In contrast with the more hedonistic Dubai, Abu Dhabi wants to portray itself as a capital of culture. Hence the museums and cultural infrastructure. Dubai and Abu Dhabi wish to be seen as "world class" in different ways.

[353] A common delaying tactic consists in that after a tendering process has finished, the client re-issues the project for tender, forcing the interested companies to do a new (cheaper) bid for the project. This tactic has been used in key projects such as the Al Rabiya Gallery Complex and in the Abu Dhabi Louvre (2012).

[354] Dubai's economy, more reliant on financial markets than Abu Dhabi's, suffered dramatically with the 2007 global economic downturn. A NYTimes story famously recorded how laid-off foreigners abandoned their cars at the gallery complex to escape the crisis. Robert F. Worth, "Laid-Off Foreigners Flee as Dubai Spirals Down," News, *NYTimes.com*, February 11, 2009, http://www.nytimes.com/2009/02/12/world/middleeast/12dubai.html?pagewanted=all.

have brought together realities that rarely co-exist: the glossy world of urbanists' visions of Abu Dhabi and the less glamorous realities of the context of its production. I have sought to ground these critiques in the context of architectural and city production in Abu Dhabi, to complicate it as a terrain of multiple interests exceeding the professional spaces and discourses of architects and engineers. I have paid special attention to social and critical perspectives on the production of the built environment.

Abu Dhabi and Dubai critics have focused on the ways in which architectural projects enact a "representational politics" aimed at legitimizing UAE's "ruling bargain" and the ethno national regime of power it indexes. Fair or not, this criticism is useful to highlight a conflict between the progressiveness of architects —who often celebrate democratic values, individual self-expression, and freedom—[355] and their role as service professionals. Frank Gehry, for instance, describes himself in an interview as

> ...a do-gooder liberal, because that's why you go into architecture, at least I did —to do things for people. I think most of us are idealists. You start out that way anyway. I didn't have any interest in doing rich people's homes; I still don't.[356]

And discusses architecture as a form of self-expression and individual freedom, attributing it political significance.

> There's a drive in us to express ourselves in some way or form. We pick up whatever material's available. It's primitive. Kids see sand on the beach and build and show their parents: "Look what I did, mama." It's necessary to us. Some cultures tried to stop people from expressing themselves. In China, for example, under Mao the Communists tried to stop individual expression. For them the payoff was a society of equality. The problem, of course, is that it didn't work. Ultimately you can't repress individuality, even though you can try. People may live and work in uninspiring environments, but look inside them. Look at the painted walls. Look at the decorations. People rebel even in the most controlled office environment where you're not allowed to do anything and yet you'll see the little bulletin board in front of a person's desk and it has their photos and clippings and cartoons and whatever else.[357]

Moreover, according to Laurence Chollet,[358] one of the reasons Gehry dropped out of the Harvard Urban Design program before finishing his degree was that, during a meeting, one of his professors discussed his "secret" commission to design the palace of right-wing Cuban dictator Fulgencio Batista.[359]

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[355] Gehry:" Sheff, "Interview: Frank Gehry."

[356] Ibid.

[357] Ibid.

[358] See Chollet, *The Essential Frank O. Gehry*, 112..

[359] Before being overthrown by the Cuban Revolution Batista was Cuba's leader in two periods: 1940-1944 and 1952-1959.

Despite discussing his work as a representation of democratic values and individual freedom, Gehry's own pragmatic response to the criticisms about his recent oil-rich monarchic clients seeks to reinforce the architect's role as a service provider, as someone who doesn't get to choose his clients. Gehry construes himself as an architectural version of Ong's flexible citizen: a free agent engaged in self-expression, instead of a political actor.[360] Is this apparent disengagement with politics perhaps a condition of professionalism?

The issue of Gehry's politics comes up in an informal conversation with a member of the firm. Discussing how critical voices in the left have come to see Gehry's work as a symbol of architects' complicity with "predatory" capitalist practices he asked simply "Why would people criticize Gehry for being a capitalist if he exists within a capitalist system?"[361]

The architects Frank Gehry and our very own Bernd Lutz *seem* unaware of the political spheres within which they operate. Their dependence on their clients' commissions to do their work may be part of the explanation. For the architects, figuring themselves as service providers, questioning such arrangement is not only outside their scope but also against their interests.[362]

It's almost certain, for instance, that Bernd Lutz is aware of the harsh reality faced by workers in his project, and yet he chooses to protect himself by discussing the social context of Abu Dhabi in an entirely positive light. He may fear that if clients have access to his statements, it may jeopardize his position.[363] BJ, on the other hand, sees problems in the communication with workers, but only those that affect her professionally. When asked more directly about the issue, both abided by widely circulating rationalizations about labor in the UAE positing, among other things, that even though living conditions are not "very good," migrants *freely chose* to be there. Subsidiary rationalizations are, first, that migrants are better off in the UAE than in their home countries, and second, that "they can leave whenever they want." However, as this chapter records, different kinds of evidence contradict these conceptions.[364] The historical reticence of architects like Gehry, BJ, and Lutz, to embrace the difficult questions posed by the political context of their practice has led scholars like Margaret Crawford to posit the impossibility of a "critical" practice of architecture.[365] Architects' dependence on clients and capital, the criticism goes, impedes the independence criticality demands. However, while architecture "provides the most effective

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[360] From a comment by Lucy Suchman.

[361] From an informal conversation in Abu Dhabi.

[362] A much quoted Upton Sinclair expression says "It is difficult to get a man to understand something, when his salary depends upon his not understanding it! Upton Sinclair, *I, Candidate for Governor: And How I Got Licked* (University of California Press, 1994).

[363] Despite consent and acknowledgement that all interviews would be anonymized.

[364] In a demolishing social critique of the profession, Ghirardo [RE-CHECK] suggests that this is a result of elite architect's egotistic concern with "experimental" agendas related to their design process —an attitude echoed by Bernd Lutz's fascination with the "amazing" and "beautiful" designs permitted by the conditions of the UAE. Ghirardo, *Out of Site.*

[365] See "Can Architecture Be Socially Responsible?" In Ibid. Also, Victor Margolin, *The Politics of the Artificial: Essays on Design and Design Studies*, 1st ed. (University Of Chicago Press, 2002).

symbolic expression of the state's presence,"[366] it's important to note that architects are not alone, *nor are they the crucial players*, in its planning and deployment. Instead, a diverse group of professionals is responsible for the shaping of cities like Abu Dhabi. Kanna describes this group as

> ...the intersection between local elites (the family-state and allied landlords, development firms, and various official and quasi-official technocrats and intelligentsia who share the family-state's and developers spatial ideology) and transnational actors such as journalists, academics, and, not least, architects who work in the UAE. All of these might be called, after Gramsci, traditional intellectuals, manipulators, and disseminators of hegemonic representations, in this case of urban space."[367]

Heteronomy

Critical accounts of contemporary architecture concerned with its elicitation of the socio-political consequences of "ruling bargains" —and with the obfuscation of the ugly aspects of its coming-to-being— should thus acknowledge the complexity of actors and economic forces involved in its production. Simplistically seeing architecture as a mere driver or neutral expression of such forces respectively reinforces myths of architectural autonomy and negates architecture's own socio-material specificity.

The schism between the progressivist rhetoric of architects and the connivance of their trade with regressive politics is, nonetheless, problematic.[368] In "The Global Architect," Donald McNeill argues that the star system in architecture, by reinforcing myths about architecture's autonomy of its social and political context, is instrumental to the urban entrepreneurial "moment" UAE cities exemplify.[369] The decontextualized buildings and people of Abu Dhabi's urban visions exist as deletions of the country's political regime, and the social and physical scaffoldings that sustain it. In this sense the mobility of both

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[366] Larson, *Behind the Postmodern Facade*, 18.

[367] Kanna's analysis crucially borrows from Lefebvre the use of the term "urbanist" to refer to this larger social group involved in the production of space. "Urbanism" refers thus to "an ideology and a set of discourses consisting of representations deployed in specific projects of the imagination of the urban." Kanna, *Dubai, the City as Corporation*, 83.

[368] McEwen traces the relationship of architecture and power to Vitruvius and Caesar. "In what way did [the buildings] record power? Essentially, according to Vitruvius, by increase. *Auctoritas* in buildings is a concomitant, variously, of increased spending, of greater richness of materials, of grander spaces, of heightened contrast in the light and shadow of a peristyle, of bigger columns and more of them. The *magnificentia* taken as the cause or consequence or both of *auctoritas* has to do, literally, with magnification. *Magnus facio,* 'I make big.'" McEwen, *Vitruvius*, 38. in Dejan Sudjic advances the provocative idea that works of architecture built as representations of the State's power may in fact be related to regime change. "But Haussman's Paris was not simply the product of imperial megalomania. Without it, France would have been a poorer and less commanding state." Sudjic, *The Edifice Complex*, 375.

[369] "Starchitecture, which privilieges the role of the architect as aesthete and genius of pure form and which elevates a few notable architects, investing them with almost super human powers of theoretical and aesthetic insight, is well suited to the demands of cities on the make." McNeill, *The Global Architect*, 82.

the architect and the laborer enact, in Lucy Suchman's words, a form of "conscription," but "in one case it liberates from responsibility, while in the other it effectively enslaves.[370]"

The explication of architecture's complicated relationship to power resists simplification and exceeds the scope of this study,[371] as it may be a structural conundrum of the social role of the architect. With this problematic landscape as a background, I zoom into the socio-technical practice of *Building Information Modeling* (BIM) and discuss its aspiration of becoming a *lingua franca* for design and construction.

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[370] From an email conversation with the author.

[371] Architects and architecture scholars have discussed alternative models of practice that renegotiate the client dependency that characterizes architecture. See forthcoming "The Right to Architecture" by Nasser Rabat in Thresholds, Revolution.

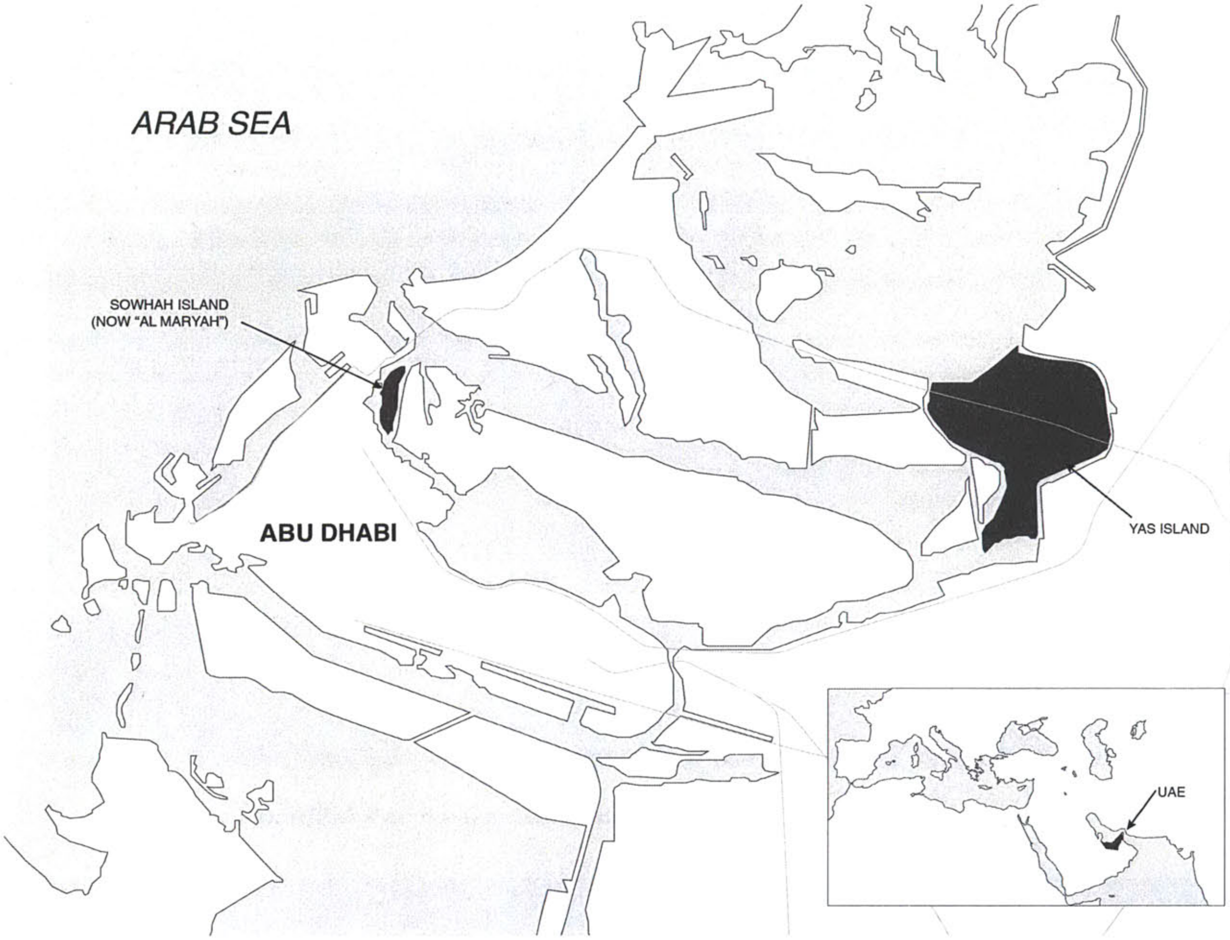

Figure 23. **Map of Abu Dhabi.**

Figure 24. **A barrier hiding a construction site is used as a billboard to present a suburban landscape.**

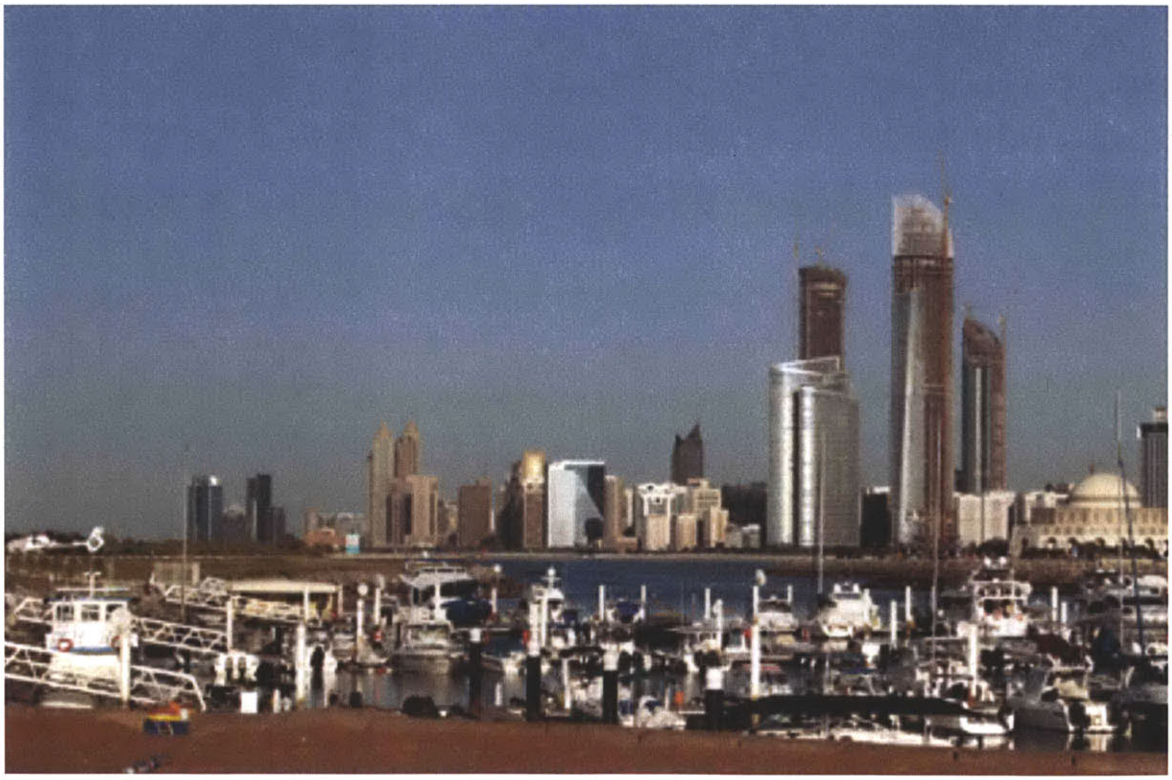

Figure 25. **Abu Dhabi downtown seen from the Marina Mall parking lot.**

Figure 26. **At the end of the day a bus takes workers back to the camps.**

Figure 27. A worker walks in the in-between spaces between the highway and a labor camp.

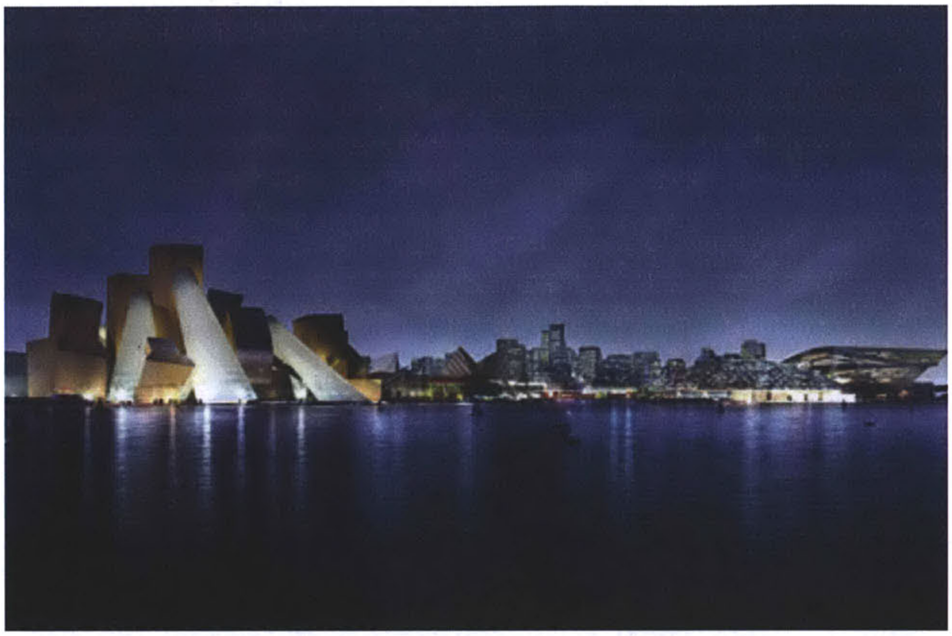

Figure 28. An "artist's rendering" of the Saadiyat Island project. On the left side of the image is the Abu Dhabi Guggenheim museum by Frank Gehry. On the right side, Zaha Hadid's performance art center and Jean Nouvel's Abu Dhabi Louvre.

Figure 29. By 2011, only a small percentage of Masdar City has been built. Masdar Institute (right of image) stands in isolation surrounded by highways and construction cranes.

6. BIM FROM THE FIELD: SEEKING A *LINGUA FRANCA*

Introduction

Outline

> A lingua franca (or working language, bridge language, vehicular language) is a language systematically used to make communication possible between people not sharing a mother tongue, in particular when it is a third language, distinct from both mother tongues.[372]

Latour argues that the actions taking place in a biology laboratory "can be ordered by looking at how scientists transform rats and chemicals into paper."[373] In a similar voice, I would like to suggest that the actions taking place in the "laboratory" of BIM coordination can be ordered by looking at the way in which *drawings* are transformed into *buildings*. In this chapter, I provide a critical account of the situated practice of BIM coordination. This chapter seeks to see the socio-material worlds of BIM through an empirical lens,[374] placing interpretive emphasis on the considerable technical —and discursive— efforts invested in the rhetorical construction of BIM as an infrastructural technology for *design to circulate*. Looking at two projects in Abu Dhabi —a high-end mall and a gallery complex—[375] I seek to interrogate BIM's aspiration to become universal: not only a center, but also a transparent *lingua franca* for design and construction.

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[372] Viacheslav Chirikba, "The Problem of the Caucasian Sprachbund," in *From Linguistic Areas to Areal Linguistics*, Pieter Muyksen., Studies in Language Companion 90 (John Benjamins Publishing Company, 2008), 31, http://independent.academia.edu/ViacheslavChirikba/Papers/571530/The_Problem_of_the_Caucasian_Sprachbund. Cited in Wikipedia contributors, "Lingua Franca," *Wikipedia, the Free Encyclopedia* (Wikimedia Foundation, Inc., June 19, 2012), http://en.wikipedia.org/w/index.php?title=Lingua_franca&oldid=498349831.

[373] Latour, *Reassembling the Social*, 2. Describing the ethnography of scientists in a biology lab in Bruno Latour and Stève Woolgar, *Laboratory Life: The Construction of Scientific Facts* (Princeton University Press, 1979).

[374] In "Plans and Situated Actions," a crucial study of human-machine communication, Lucy Suchman observed that, in the Western intellectual tradition, plans tend to take a preeminent role in accounts and interpretations of human action. Suchman proposed to re-specify the study of action through empirical accounts of "situated actions." See Lucy A. Suchman, *Plans and Situated Actions: The Problem of Human-Machine Communication*, 2nd ed. (Cambridge University Press, 1987).

[375] The project and organization names and other details have been omitted or transformed to protect the anonymity of people and the confidentiality of organizations.

Contractual dimension of the *Albertian split*

I have described the architect's unbinding from the worlds of construction and labor —the *Albertian split*— as a defining trait of the architect's discipline. In the contemporary practice of building production, the gap[376] exists as a culturally established and legally enforced boundary. This boundary plays a major role in structuring the trades involved in the production of the built environment. In the Emirati context, the typical form of project organization is a vertical structure involving the client —a government investment arm— and a developer —hired by the client— for managing the totality of the project. The developer manages both the design and construction services through separate contracts.[377] Once the architect has designed the building, the developer releases a set of drawings and models about the project for "tender," a competition process in which different companies compete for the contract by making detailed plans for the building's execution. During the tender process bidding companies work for months on the development of the plans without certainty of getting the project. For the financial risks involved, bids are often developed by alliances, or "joint ventures," between two or more engineering consultancies and construction corporations. The joint ventures allow companies to distribute the risk, share resources and the skills of their personnel, and improve their chances of being awarded the contract. In Abu Dhabi, contracts can often be measured in the billions of dollars.[378] During the tender process, the goal of the bidding organization is to produce detailed and convincing execution plans that demonstrate to the developer (and to the client) their capacity to bring the project into completion faster and cheaper than their competitors: week by week schedules of the construction, material supply management strategies, logistic path planning accounting for the use of machinery and personnel on site, labor transportation plan, simulations of critical aspects of the construction process, development of design alternatives to reduce the cost components of the architect's proposal.[379]

"Frozen" designs

To develop their proposals, bidding organizations are given access to a limited set of descriptions of the project known as the "tender package." The package usually contains a set of the architect's drawings known as "Issued for Construction,"[380] and (sometimes), a 3-D model. Both the drawings and the models

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[376] See Chapter 1.
[377] This modality is known in industry as *turn-key*.
[378] The construction of the TWM is estimated in 1.3 billion dollars.
[379] This process is known as "value engineering."
[380] This set of drawings is usually referred to as "the *IFC*." Not to be confused with the *IFC* (Industry Foundations Classes) digital format for BIM. See Chapter 3.

are delivered in digital formats that restrict their use to visualization and reference[381]. The 2-D drawings —static by nature— for instance, are commonly delivered in Adobe's .PDF format, or in "view-only" versions of CAD files. The 3-D model is encoded in a "for-reference-only" format, such as *Autodesk*'s .NAV format.[382] Because of its restrictions, BIM consultants commonly describe the model provided by the architects as "dead," or "frozen." The 2-D drawings, and the "dead" models provided as part of the tender package, constitute legally binding documents and can only be modified through intricate channels of institutionalized verification and approval. The restriction to the editable files of a developed design is a legal provision intended to protect the architect's intellectual property.[383] Moreover, during the tender process described above, the restriction is understood as a way to keep a level playing field for all bidders. Under this view it would be problematic, for instance, to include in the tender package a 3-D model that requires proprietary software that not all participants have access to.[384] Through the contractual pipeline of construction, the building's designs are thus transferred, first, from the architect to the client/developer, and then to the competing construction teams, as static —"frozen"— representations of the architect's design.

These restrictions on information use force the bidding organization to re-construct the design using their own systems of description. In this context, the ability to quickly and precisely re-create the architect's designs allows builders a key competitive advantage towards winning the contract. It is in this context that *Gehry Technologies* seeks to position itself as a provider of a technically precise model allowing the bidding organization to produce more detailed execution plans, more accurate estimates of material and labor quantities, more credible logistic scenarios, and more relevant design alternatives. Increasingly, the "BIM certified[385]" practices of companies like *Gehry Technologies* fulfill a contractual requirement that gives legitimacy to the bidding organization before the client and developer.[386]

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[381] The formats used can be opened in freely available software systems, like Adobe Acrobat Reader, or AutoDesk's viewers.

[382] Navisworks is a 3-D software by *Autodesk*. Like Adobe Acrobat, Navisworks can be downloaded for free from the Internet, as a viewing-only tool. While it's not meant to edit geometric elements, it is possible, however, to selectively export geometry from Navisworks into other editable formats.

[383] Design development models and drawings in the US are subjects of copyright: "The Architectural Works Copyright Protection … extended copyright protection to a class of works called "architectural works." The design of a building is defined as embodied in any tangible medium of expression, including a building, architectural plans, or drawings. Moreover, the work includes the overall form as well as the arrangement and composition of spaces and elements in the design." See "Intellectual Property Rights of Architects in Plans - Architects," *USlegal*, n.d., http://architects.uslegal.com/intellectual-property-rights-of-architects-in-plans/.

[384] This is commonly drawn as an argument by the standards organizations discussed in Chapter 3 to push the universal adoption of *.IFC* as single 3-D BIM format.

[385] An issue of standards: The software Digital *Project* is a "BIM certified" system according to BIM Smart, the organization behind the *IFC* initiative.

[386] Developers are contractually obligated to have a BIM provider to support the construction coordination. See Appendix for a discussion about BIM standards.

The gap between architects and builders is thus not only legally enforced by the contractual arrangements regulating the industry, but also a device for structuring the relationships between different professional groups. The barriers to information sharing force the bidding organization to re-describe the project, while the contractual requirements demand that a BIM certified organization supports the building process. *Gehry Technologies* represents itself in this context as a translator of the design into the language of the builders. Its market proposition is, in this context, to bridge the worlds of design and construction.

Legal boundaries to digital flows

Sometimes the legal barriers to information sharing restrict the circulation of digital information within the same organization. During the development of the Abu Dhabi Louvre, for instance, *Gehry Technologies* was closely involved in the design development of the architect's proposal. According to Arda Bağdaş[387] —a Turkish engineer and a Project Manager with *Gehry Technologies*— a team from the office in Paris assisted the office of Jean Nouvel during the design process of the building's unconventional dome, producing a highly detailed BIM. When the design phase was finalized, the developer released the "tender package" and *Gehry Technologies* was hired as a BIM consultant by one of the bidding organizations, to support their bid. However, *Gehry Technologies* was unable to use the BIM model it had previously developed. The team assisting the bidding organization thus had to build a new model from scratch from the drawings (that had been originally extracted from the 3-D model it had created).

The lack of sharing and its immediate consequence, the required work of re-constructing the 3-D model, are common sources of frustration for some of the project's participants. Bağdaş who participated in the Louvre bid in both the Paris and Abu Dhabi teams, described the restricted flow of information between the construction and design teams as circuitous and nonsensical. More than a technical problem, he sees it as an artificial constraint in the workflow. He explains his frustration:

> We helped build the design model, and... Because of the legal constraints you cannot use this design model if we work with the contractor! We cannot use the same model again in construction because it's property of the architect, and you're not allowed to use it. And then you end up building the model again based in the construction documents. And where do the design documents for the construction come from? They were extracted from the BIM model! So, do you see the loop? You create a design model, you extract the drawings from it, but you can't use the model. You need to use these models to re-build the construction

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[387] Pseudonym.

> model, in a more detailed fashion and report discrepancies. So to me it's a workflow problem. It's not a technical problem.

Bağdaş sees the legal framework regulating the profession as an artificial barrier to the fluid circulation of digital design information. Like Witt and Eastman in Chapter 3, Bağdaş sees the opportunity of BIM to streamline design and construction by transforming the flow of information —and further reducing the architect's autonomy from construction.

> The contractors need to be hired early on, in the early stages of the project ... While the architects are doing the design they need to be consulting with the contractors on what is buildable and what is not, because contractors have so much experience in... in building things, and they know what can be done and what cannot be done... In the end it's going to go this route anyway, because whatever the architect is going to design, the contractor will look at the drawings and say oh we cannot do this... Let's send an RFI, the architect will look at the RFI[388] and so... You can eliminate all of this redundancy by just bringing in the contractor early on and consult him on "what do you think?" or "what can be done?"... I mean. Again, it will never be that easy, the lines of responsibility will become a little bit vague... and... And that's why probably no one has come with the best way of delivering a project that way, but... Um... I think without this step BIM is not really utilizing its full potential.

From a different managerial perspective, however, the re-description of the project is crucial to engage the project and the people involved in its planning. Alexander Barton[389], also a BIM project manager, sees the process of creating the 3-D model from the 2-D drawings as a candid transaction between street merchants:

> You [referring to me as the client] have this project, and you think it costs "X." And then I come [referring to himself as the contractor] and I look at it. And I draw it again. I make my calculations, talk to my experts. And then I go back and tell you: "No. It costs 'Y'". Then you say " um... let's see." And that's when we start talking business![390]

In Barton's persuasive account of the bid, re-description is an exercise in business assessment. Barton — a mechanical engineer with a background in finance— understands that by centralizing the description

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[388] RFIs (Requests for Information), are documents that circulate between actors in a design-construction process. Typically, these documents are addressed to the designers or the client by a member of the coordination or construction team, with the intention of clarifying an issue on site. RFIs are official documents that are archived and used to moderate conflicts between parties. Large projects have specialized teams devoted to write, manage, respond and archive RFIs.

[389] I use a pseudonym to protect the anonymity of the subject.

[390] Paraphrased from a personal conversation with Alexander Barton.

apparatus of the project in a *Digital Project* model, a team of BIM consultants can become crucial players in the larger bidding organization. The BIM model is expected to allow all relevant participants to inquire the model's attributes in order to facilitate estimation, inspection and dissemination of information about the project. From Barton's managerial perspective, the set of IFC drawings representing the architect's design, are the "raw" material to be transformed —first into a Building Information Model, and ultimately into a building. The production of the descriptions that mediate this transformation, and allow actors to agree, is one of the key services he bills to clients [Figure 33].[391]

2-D and 3-D

Despite the ambition of centrality advanced by the advocates of BIM, drawings, and not 3-D models, continue to be the authoritative[392] documents in design and construction. This poses contradictions for those practices that rely fully on 3-D information during the design phase. In an interview, Bağdaş illustrates this point with an example, recalling a clause in the contract between the builder and the client for the Qatar National Museum (also designed by Jean Nouvel) that specified that if there was any discrepancy between the 3-D information and the 2-D drawings, drawings had priority over the model.

> [In the Qatar National Museum] the drawings were extracted from the design BIM model, and in the contract documents it says that whenever there's a discrepancy between the model and the drawings, the drawings are superseded. So… So, by default anyone working on the project, legally they have to think this way. The drawings take more priority. And we tried to change this mentality a little bit on the project…

The (contractual, but also cultural) primacy of drawings over models posed a contradiction, as the 2-D information was not originally *drawn* anywhere, but had instead been instead *extracted* from the 3-D model.[393]

> You know how the QNM is built of intersecting discs at different angles, different locations. So… in the drawings there was a disc schedule giving all the information about uhm… The coordinates of every disc, and the angle of the symmetry plane of the disc, all of the parameters defining the geometry of every

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[391] While drawings are a universal interface, 3-D models require skills and technologies that are not necessarily available to all participants. This is particularly true of software systems such as *Digital Project*.

[392] See the discussion about the architect's "Auctoritas" in Chapter 2.

[393] In a public presentation, Andrew Witt referred to the process of extracting the 2-D information from a 3-D model as model-centrism. In his talk, he advocated the idea of a transition between a drawing-centric understanding of design-construction practice, and a model-centric one. As Bagdas anecdote shows, the legal culture does not comply (yet, Witt would say) with the model-centric view of practice. Witt, "Concurrent Design."

> disc in the project. So… We were doing like a model audit report at the beginning of the project to see how much [the model] is compatible with the drawings. And… We found that some of the coordinates in the disc schedule, which is an IFC drawing, does not make any sense. If you try to build the disc with these center coordinates … you will build it 5 blocks away from the museum! [laughs]

For engineers like Bağdaş, BIM technology has the potential to reduce redundancies and optimize an industry that is "lagging behind." For managers like Barton, in contrast, the barrier to information sharing —the *gap*— is simply part of the landscape of practice. He embraces with pragmatism the processes of translation, re-description, and re-drawing that the promotional discourses of BIM promise to eradicate. From this perspective, the BIM organization role in this particular context of practice is validated by the contractual and cultural separation between the design and construction work. Recreating the design from the tender drawings can be a challenging feat, in particular if the building's shape is unconventional and requires sophisticated instruments for its description. For a bidding organization, the ability to create such model is crucial to demonstrate a full understanding of the project. In turn, for *Gehry Technologies*, the ability to produce such model is one of the crucial tenets of its business proposition, and a crucial claim to their technical expertise as providers of the infrastructures of *design*.

Enforcing (and translating across) the split: the RGC project

Enlivening designs

The Al Rabiya Gallery Complex (RGC) is an expansion to the Abu Dhabi Gallery complex designed by Berenger & Fallon. When the project was released for tender, *Gehry Technologies* was hired by a joint venture to develop the *Building Information Model* for the project. The building's design comprised four curved exhibition wings converging into a large central hall. The most distinctive aspect of the building's design is the unconventional shape of the exhibition wings' envelope[394] and the center space's roof. The exhibition wings are enveloped by undulating surfaces clad with stainless steel. The wavy shape of the exhibition wing is meant to resemble desert dunes, in reference to the surrounding desert.[395] The center

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[394] In architectural language, a building's "envelope" is the enclosing element. Commonly, an enclosing element that can't be accurately described either by the words "roof," or "wall" will be called an "envelope."

[395] Several projects in the Gulf are explained with metaphors about references to local culture or landscape. Architects commonly use metaphors like this to create a connection with their clients. The design of the *Sheik Zayed National Museum* by Foster and Partners, for instance, is explained as a reference to the feathers of the falcon (falconry is considered a national sport in the UAE). The design of the *Qatar National Museum*, by Jean Nouvel, is explained as a reference to the mother of pearl formations found in the Qatari desert. The *Louvre Museum* (also by Nouvel), is explained as a reference to the space of the market, or *souk* —although this is a direct architectural reference.

space's roof, also clad in steel panels, resembles a ray fish, and is sustained by a set of steel girders spanning the main terminal area.[396] The longest of the structural girders is 180 m long —a significant engineering challenge.

In Chapter 4, *Digital Project* was described as a *parametric* environment, akin to a mechanic's table where users operate in a Newtonian world of forces and constraints. During the tender process for the Al Rabiya Gallery Complex, a team of BIM consultants used *Digital Project*'s Newtonian arsenal to *construct* an "enlivened" model of the terminal from the "frozen" models and drawings in the tender package[397]. This section illustrates the *tectonics* of such descriptions by describing the modeling process of the Al Rabiya Gallery Complex (RGC) [Figure 34].

Plans for the plan

Many of the hundreds of drawings in the tender documents comprise the traditional forms of architectural description. Set-out and building plans, sections, construction details, and elevations describing all aspects of the project in minute detail. Because of the unconventional shape of the exhibition wings' envelopes, and of the center space's roofs, other forms of description are provided to allow for the precise re-construction (and in-fact, construction) of the building. Abstract diagrams describing the geometric principles, and mathematical equations describing the curvature of the envelope. Through both diagrams and equations, the architects describe the algorithmic process through which the curved shape of the exhibition wings' envelope and center-space roof can be recreated. While the center space roof was a unique element in the project, the exhibition wings' envelopes were, despite their irregular appearance, successions of repetitive elements, paced in accordance to the structural axes described in the project's main grid. Each exhibition wing, excluding its end, was a succession of four or five similar modules. The section of the envelope corresponding to any module describes one interval of the envelope's sinusoidal wave. The precise shape of a module's envelope —the interval—was determined by a succession of arc elements. The starting and middle arcs of the succession are the "valley" and the "cusp" of the sinusoidal wave; the minimum and maximum states of a mathematical progression. The arcs in-between these boundary states are interpolated by applying a parametric equation that calculates

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Through the construction of a poetic narrative about the project, architects engage the clients' imaginations *and* secure commissions.

[396] The "design model" of the ARGc was developed in the *Generative Components* plugin for the software *Microstation*, but the reference model in the tender package was a "frozen" model in the *Navisworks* format (.NAV).

[397] The ability to produce a precise digital model from which reliable information can be derived —a "re-enlivened" representation— is key for building contractors to establish credibility before their potential clients. Moreover, as shown by Barton's rendition of the bid, the model is both a way for the builder organization to appropriate the design, and second, a form of building trust between the parties. Digital *Project*, the firm's signature software system, plays a key role in creating a "live" model from a "dead" one.

the position of each of the control points in any given arc. The parameters of the equation are the minimum and maximum X and Z values for that given point, and a *t* value representing the place of the arc in the module (t=0 is the starting arc, and t=30 is the final arc). The arc element itself is defined by the interpolation of a curve between the control points. The succession of the 30 arc interpolations describes the progression between the valley and the cusp states of the module. A symmetric interpolation results in the 60 unique arcs of the exhibition wing module, producing the distinctive "dune" effect. But first, the abstract representations in the drawings, diagrams, and in the "dead" reference model, had to be encoded into the software. I now turn to give a *personal account* of my role in the modeling process.

Building the plan: first layer of automation

After months of dealing with subcontractors in the BIM coordination of another project I was —to put it mildly— eager to work on the RGC model. I had to first familiarize myself with the architect's drawings and, in particular, with the mathematical descriptions of the building's unconventional shape. The project was very well documented —thousands of drawings and a for-reference-only *Navisworks* 3-D model [Figure 30]. To study the materials I appropriated a small room in the bidding organization's offices for several days, putting drawings on the walls and tables, highlighting important information, and making countless sketches on paper.

I slowly started by laying out the project's setout grid from the geo-located points in the drawings. The setout described with precision the location of the building in the world, and the grid of structural axes organizing the project, with an accuracy of millimeters. I focused on codifying the 2-D diagrams and mathematical equations in the tender documents, into a structured 3-D building information model of the exhibition wings' envelopes. I created a parametric description of the arcs. Instead of a singular representation of a single arc, I used a *power-copy* —a category of object in *Digital Project* allowing the user to define geometric elements in accordance to inputs. I specified the position of each of the control points of each arc by encoding the parametric equation provided in the drawings into the *power-copy*. To produce a certain instance of the taking as arguments, first, the position of the arc along the module, and second, the minimum and maximum X and Z positions of each point as specified in the tender documents. As parameters of the object, I added a variable specifying the arch type, which changed the minimum and maximum X and Z positions of each of the arch's control points; also, a parameter for representing the position of the arch within the module (a set from 1 to 30, considering that the modules were symmetric). Finally, I encoded in the *power-copy* the polynomial equation for the sinusoidal variation of the exhibition wing's roof surface in relation to these parameters. The resulting parametric system could calculate the position of each and every control point in the arch, taking into account the "type" variable defining the minimum and maximum range of the X and Z coordinates of the point —as well as the position of the arch in the module. The resulting parametric object —the *power-copy*— was 46 Kb on disk, and could be used to produce several thousands different arc configurations.[398] The inputs for each arc were 3 points defining the plane of each one of the 60 module's interpolations (generated also parametrically from a single object). Using this method, I was able to "calculate" the arcs for several of the modules of the exhibition wings' envelope, and locate them in the project's grid. Each one of the arcs in a module is unique. Together, because of the logic of the parametric equation, the arcs describe a smooth interval of the exhibition wing's sinusoidal undulation. With the arcs in place, a surface could be *lofted*[399] to create the *design surface* of the exhibition wings envelope.[400]

The idea was to devise a system that could be used to represent *any* exhibition wing module. By changing a parameter in the power copy of the base, like its length or radius, the whole module would adapt, changing the disposition of the arches and therefore the surface. Suddenly, we didn't just have a exhibition wing module, but the logic of a system to create *any* module.[401] By this time, while the production of each arc's shape is parametrically determined —and therefore semi-automated— the arc *power-copy* had to be activated manually for each of the individual arcs —30 times in a symmetric module, 60 in a non-symmetric one. Despite the automation of the arc-generation process, creating a description of a module was time consuming. A new layer of automation had to be added to the system, in order to generate the building envelop in its entirety.

Barton, who was managing the project, used screen shots of this early model to create a document proposal that expanded the BIM team's scope of work in the bid to include detailed simulations of the building's construction, the synthesis of the concrete model —developed by a subcontractor— and a detailed building information model of the exhibition wings and the center space roof. Besides the "design surface"[402] of the building's envelopes, the proposed model would include the underlying steel structure, glazing, and cladding of the building. Once the scope was approved and the contract expanded, Barton organized for Bağdaş to participate in the model's development. After introducing Bağdaş to the logic of

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[398] Bağdaş referred to this parametric construct as "light in terms of data, but logic-heavy."

[399] "Loft" is a common command in 3-D modeling software, which produces a surface object from a series of lines.

[400] A common parametric modeling strategy is to use a surface as "driver" of other components. In this strategy, a surface —often referred to as a "design surface"— is at the top of a hierarchical system of geometric elements depend on the surface. Because of this relationship of dependency, these elements are said to be "driven" by the surface. The idea of the surface as a driver of architecture is a crucial tenet of *Gehry Technologies's* work. In 1997 Dennis Shelden, then director of computing at Gehry Partners, wrote a doctoral thesis that approached the subject. In the thesis Shelden suggests that the ability to create precise and detailed building descriptions driven by surfaces of unconventional shapes (afforded by software systems like CATIA) allows architecture to escape the "tyranny" of Euclidian, orthogonal forms. Shelden, "Digital surface representation and the constructibility of Gehry's architecture," 25.

[401] Daniel Cardoso Llach, "Fieldnotes", n.d.

[402] "Design surface" is the term commonly used to refer to the outer surface of the project. While it doesn't exist as a construction element, it describes the overall shape of the project and serves as a reference for all elements.

the project, we set out to formalize the mathematical "recipes" encoded in the parametric system I started into a more robust system for generating the whole project. Bağdaş, a seasoned BIM expert and programmer, suggested a re-organization of the project's folder structure. Because a model's folder structure and nomenclature determine the future forms of usability of the model, this task was the subject of several hours of serious consideration [See Figures 31 and 32].[403]

A model factory: second layer of automation

Bağdaş wrote scripts for automating the instantiation of the *power-copies* generating the arcs —adding a second layer of automation to the system, and greatly reducing the time required for producing the modules. I developed new sets of "power-copies" that took the arcs as inputs and produced the envelope's cladding and glazing. Later, Bağdaş developed a *power-copy* for generating the underlying steel structure,[404] and a series of rules for evaluating the panel's deviation from the design surface at "instantiation time."[405] The ruleset included color-coding each panel according to its deviation index, producing a gradient image identifying the areas of the module where deviations from the original surface were critical —thus informing a decision about alternative ways of cladding the surface [Figure 35].

With the system in place, it takes the computer around 15 minutes to produce a module. Each element created is placed in 3-D space, and within the project's "tree" —defined in part by the folder structure— the hierarchical representation of the model in *Digital Project*'s interface. An "instruction" document for the model's *operation* recorded the steps a *user* had to follow in order to produce a particular module. An accompanying datasheet contained the parameters for each of the modules. The resulting model would give the bidding organization the ability to make well-supported estimates about material quantities, constructability studies, etc. More importantly, by "constructing" a precise and detailed representation from the drawings, equations and diagrams, the bidding organization could claim that the unconventional geometry of the building's roof was entirely under their control [Figure 36].

Because of the linkages between numerical values and geometric elements in the model, the shape of the envelope could be transformed with relatively little effort. The capacity of the model to change was highlighted to the bidding organization as a mechanism to produce simpler design alternatives [Figure

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[403] As discussed in Chapter 3, unlike most available software systems, a Digital *Project* "project" is a system of linked files managed by a "project" file that administers linkages to a potentially large number of other files. The hierarchy of the linkages and their structure makes planning a BIM's folder structure and nomenclature a very crucial phase. Decisions taken at this stage are fundamental to the whole Building Information Model. Striking a balance between level of detail and simplicity is crucial to make the model a readable and usable information structure. The key variable to take into account is the desired complexity of the files.

[404] Such approach to surfaces, in which a surface is the "driver" of a project's elements, is one of the crucial forms of expertise that Gehry Technologies is known for developing

[405] Meaning that the rule is applied during the automated instantiation of each panel.

37]. Rather than creating a new design from thin air, the parametric model would allow us to just *tweak* the architect's original design[406] while preserving (or so we believed) the integrity of the architect's "design intent." The building's envelope, being the most expensive and challenging component of the project's construction, was the focus of the "value engineering"[407] efforts of the bidding organization, making it a potential space for an expansion of *Gehry Technologies*'s scope of works. However, a team of architects hired by the bidding organization, seated directly across the *Gehry Technologies* team, was assigned by the bidding organization to "value engineer the design."

The boundary of design

The team of architects assigned to *value-engineer* the project saw Barton's expansionary impulse as an infringement of a cultural separation between design and construction. The BIM and the *value-engineering* teams barely exchanged a word, and yet were forced —by their proximity— to glimpse at each other's work and overhear conversations about different strategies for altering the building's design.[408] At times, tension between the two teams *seemed* to mount. During cigarette breaks, Bağdaş, Barton and I discussed ways in which *our* model could enable a simpler, more efficient structure than the "dirty marks on paper" by the *value-engineering* architects. Most of the time, however, the conflict over the role of the BIM team within the design discussions took place between Barton, who managed the project, and the leaders of the bidding organization.[409]

Even though Barton pitched to the organization leaders the model's level of detail and flexibility to modulate the shape, the contractual scopes were preserved. Instead of participating in the re-design of the building's envelope, the BIM team was asked to participate more fully in the definition of the month-by-month construction plan simulation. Meanwhile, the architect's sketches of the "new roof design" became the objects around which discussions about design changes took place. The *dirty marks on paper* drove the debate about the building's re-design.

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[406] These claims were advanced in tacit contrast with the tools design alternatives presented in "non-certified" media such as sketches and collages.

[407] Modify a design, often by simplification, with the purpose of cutting construction costs.

[408] The time invested in producing a parametric system for "translating" the architect's design intent into a precise and flexible model made it difficult for the GT consultants —myself included— to accept that a "new" logic was being discussed. This helped strengthen the claims to authority premised on the mathematical precision of the model, and on the "certified" Digital *Project* model.

[409] In contractual terms, Gehry Technologies is expected to act as "enabler" (not "proponent") of design ideas.

Trade-offs

The modeling of the RGC envelope exemplifies the realization of the idea of structured modeling that MIT engineers like Sutherland, Coons and Ross, foresaw in the early days of computing: a structured model where both data and geometry imbricate, allowing for a stricter management and transmission of design information. More than a *drawing* of a design, the model resembles a mechanical system enacting the *logic* of a design.

To what extent are parametric models flexible? In the parametric model developed by the BIM *team* for the RGC envelope, the geometric variation of the building's shape is limited by the logical assumptions taken by model's makers, expressed in the hierarchical structure of the model itself. By modifying the mathematical equations controlling the *power copies*, the BIM *team* can change the variation of the arcs and therefore modulate a different shape for the building's envelope. At the same time, shape changes demanding a different approach —not arcs but segments, for instance— are outside the system's possibilities. In Shelden's words, they are outside the model's "design-space[410]." The more structured the parametric model became, the more its mechanical logic precluded forms of variation not prescribed in it.[411] The architects in the value engineering team produced, in contrast, "dirty marks on paper:" drawings, collages and annotated plans, quickly setting forth alternatives to the original design by *KPF*.

The construction of the model, as well as its inability to harness the conversation about the building's re-design, are expressions of the key trade-off of structured models and computational representations of buildings: the more mechanically precise and "rich" a computational description is, the less "flexible" it becomes. The structured model successfully helped in producing construction simulations, quantity estimations, and in asserting the BIM *team's* technical proficiencies within the organization, for the design *at hand*. Moreover, it helped create a shared understanding of the project in the organization. However, the parametric flexibility afforded by the model proved to be a restrictive vehicle for design "exploration."[412]

Questioning interoperability concerns

Anthropologist Natasha Myers has observed, suggestively, how molecular physicists come to understand the complex molecular arrangements they study in the embodied process of making physical

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[410] For Shelden's discussion of "design-spaces" see Chapter 4. I have discussed these trade-offs in the context of personal digital fabrication in Daniel Cardoso and Lawrence Sass, "Generative Fabrication," in *Design Computing and Cognition '08*, 2008, 713–732, http://dx.doi.org/10.1007/978-1-4020-8728-8_37.

[411] See Shelden's discussion about Digital *Project* in Chapter 4.

[412] GT's claims about the "purity" of design intent were premised on the mathematical sophistication of the model, than in exploring alternatives outside the "design space" outlined by the mathematical logic embedded in the model.

and digital models.[413] The same can be said of architectural models, both at the personal and organization level. Through the "tactile" work of digital modeling, a team of specialists can intimately appropriate the shape of a building. Through the co-construction and discussion of images and models, and the associated back and forth with clients and developers, participants come to build trust and a shared understanding of a project —Barton's rendition of the bid as a street transaction illustrates this perfectly.

The contrasting attitudes of Barton and Bağdaş illustrate two forms of thinking about the "gap." In Barton's pragmatic stance, re-description and redrawing, conventionally cast by promoters of BIM as manifestations of "interoperability problems," are crucial to building trust between contractors, subcontractors, and clients. Moreover, it allows participants to build a shared deep understanding of the project. In contrast, in Bağdaş's view[414] re-description is unnecessary, wasting the possibility of sharing digital information.

What needs to be made clear is that, by making the process of re-description the target of optimization, this view targets *also* an ecological system of building production involving diverse professional groups, and traditions of trust building and work.[415] During the bidding process, the client/developer and the builder use the distances between the new and old media as a crucial space of negotiation to create the trust needed to define the terms of the project's execution. It remains to be seen how mechanisms of trust building transform as the forces of production bring us closer and closer, as BIM advocates expect, to the dream of a common, standardized language for both design and construction.

In what follows I discuss how as the legal and cultural dimensions of the industry move towards the adoption of *Building Information Modeling*, the inertia of contractually and culturally established roles generates social friction, and ad-hoc infrastructures of resistance.

The BIM coordination enterprise: building the TWM

Enacting centrality in an adverse context

Like other large, iconic projects such as the Abu Dhabi Louvre, the Abu Dhabi Guggenheim, and the Abu Dhabi NYU campus, the Abu Dhabi Thomas Wynne Mall is a franchise of a western institution. An official description of the project states that the clinic will "bring high-quality shopping facilities in an

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[413] Natasha Myers, "Molecular Embodiments and the Body-Work of Modeling in Protein Crystallography," *Social Studies of Science* 38, no. 2 (April 1, 2008): 163–199.
[414] Which follows more closely the promotional narratives of the BIM project.
[415] Michael Gallaher et al., *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*, U.S. Department of Commerce Technology Administration, Advanced Technology Program (Gaithersburg, Maryland: National Institute of Standards and Technology, August 2004).

environment equipped with state-of-the-art amenities," and that it will become the "Middle East's landmark mall." The construction of this project involves several corporate giants. The client is one of the major investment bodies in the Emirate. The developer is in charge of a large part of the Emirate's big construction projects. American engineering and management giant is the design and construction manager. The design of the project was commissioned to one of the world's largest architectural offices, and to a multi-national management consultancy company focusing on architectural and engineering services. After an open competition between different companies for the construction contract the contract was awarded to a "joint venture" of the Asian mega-corporation TEZUKA and the European giant QUATRO. On site, the joint venture between the two companies was referred to as Q+S (QUATRO-TEZUKA Joint Venture). As the projects' main contractor, Q+S hired six other companies: the traditional building trades —concrete, steel, MEP, etc.— and *Gehry Technologies* as a "BIM provider" to support the coordination of the building's design and construction. The relative size of *Gehry Technologies*'s participation (four consultants and one Project Manager) in the project was very small —amounting to 2% of the workforce involved [See Figure 38].[416]

Instead of the vertical power structures that characterize the industry, advocates of BIM imagine the organization of design and construction as a central diagram where technology is placed at the center of a ring of actors including the architect, the client, and all the construction trades [Figure 39].[417] In this diagram, the BIM provider is absent as a construction trade, but is represented symbolically at the center by the model.[418] This central diagram constitutes an imagined geography of practice where actors' roles and modes of communication are defined in relation to the technology, which demands from actors the adoption of particular protocols of information management and exchange. From this perspective, the *Building Information Modeling* project can be seen to carry an agenda of discipline and control over the participants of the design and construction process. In the stories that follow I discuss how, in the process of coordination, the desired primacy of the model is contested by contractual hierarchies and cultural conventions framing the design and construction coordination. I do so from the perspective of those "synthesizing" the model: those involved in the assemblage of structured, 3-D virtual representation, from the contributions of members of all the construction trades.

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[416] *Gehry Technologies's* engagement with the project comprises three distinct stages. The first was to support the Q+S's bid during the tender process. The second, and by far the most challenging, was to use BIM to support design and construction coordination throughout the project's execution. The third was the development of an "as-built" model, an evaluation of the completed works. According to an informal conversation with Project Manager for GT Alexander Barton.

[417] See Chapter 4, or Witt, "Concurrent Design."

[418] In Chapter 3 I discussed how, in early discourses of computational design —particularly in Negroponte's proposition— the presence of the technology and the absence of the technologist serves the purpose of portraying the technology as a neutral, passive agent.

Arriving on site

The Q+S site is the temporary building where the development of the Thomas Wynne Mall Abu Dhabi takes place. It's located in Yas Island, 40Km north of Abu-Dhabi. Wide, brand new and —by 2010— mostly empty highways give access to it. Leaving the highway that connects Abu-Dhabi and Dubai to take the Yas Island (East) exit, the driver encounters a network of wide empty highways appearing to serve nothing but an endless succession of construction sites. The scale of the infrastructure deployed on the landscape is, however, impressive. The six-lane highway is sidelined by a double row of light posts which are neither vertical nor perfectly straight —they are tilted to one side and bent slightly to the other near the middle— a gesture that, repeated ad-infinitum along the road, offers a distinctive image to the driver —as if a magnetic field had distorted a myriad wires. When it's dark, the lit wires on the highway dividing the Emirati desert from the Arabian Gulf waters, offer an impressive view —of carefully landscaped, almost futuristic, isolation. Steel structures by the intersections between the highway and secondary roads mark the spot where a future bus system will pick up passengers. The structures consist of thick steel tubes bent one over the other into an arch-like shape (a latticed sheet of doubly-curved metal between the twisted arches shades the space where people will one day wait for the bus).

6-days a week, 300 consultants and visitors take these roads to the Q+S site. Before arriving, they all must stop in a security office, leave a personal identification document, and claim a "visitor" pass in exchange. The security office is a one-storey barrack in the middle of a huge sand lot —nothing inside but a desk, with two employees and an air conditioning unit. The pass, once retrieved, gives the visitor access to a gated section of the highway that leads to a short open road ending in the Q+S site offices: a long row of about 500 m of two-storey barracks spotted with air conditioning units. The cheap building is made of plywood, painted pale yellow on the outside, and clad with fake gray wood on the inside. It is supported on a thin steel frame elevated 1 ft from the ground by concrete blocks. Inside, the AC units roar and engineers, architects, trades-people, administrative staff and laborers —all "visitors"— work on the design and construction coordination of the Abu Dhabi Thomas Wynne Mall.

Navigators, clash-detectors, and other micro-roles

Peter Galison has written about "a new mode of coordinating activities" emerging around computer simulations in the aftermath of the war "where scientists from different disciplines (different practice and language groups) could form a trading zone."[419] BIM functions under a similar premise, seeking to use simulations to form trading zones for design and construction coordination. Traditionally, coordination involves face-to-face meetings with members of all trades, each with a set of 2-D drawings describing their discipline's specific contribution to the project. Using printed copies of the building's drawings, and

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[419] Peter Louis Galison, *Image and Logic: A Material Culture of Microphysics*, 1st ed. (University Of Chicago Press, 1997). In his ethnography of simulations, Yanni Loukissas has used Galison's notion of "trading zones" to think about the negotiation of professional boundaries between engineers and architects. Loukissas, *Co-Designers*.

colored markers, participants seek to reveal potential conflicts arising from the integration of different systems. Common conflicts involve, for instance, clashes between the steel structure and drainage pipes, "I" beams crossing circulation spaces below the proper height, ducts diving into a false ceiling and creeping (uninvited) in elevator lobbies [Figure 40]. Relevant conflicts are revealed and discussed before they make it into the site —where things are much more expensive to fix than on paper. In a successful coordination meeting conflicts are found, discussed, accounted for, and a responsible party is determined to solve them. A conflict is only considered solved when the party deemed responsible amends the corresponding drawings before they are sent to the construction teams.

In contrast with the 2-D drawings of traditional coordination, BIM coordination processes focus on the interactive environments of modeling software. Instead of inspecting the building's design by overlaying sheets of tracing paper, participants gather around the projection of a digital model assembled from the different models provided by each trade. While in a traditional coordination process office assistants prepare paper drawing sets for the decision-makers' inspection,[420] in a BIM process a new kind of specialist *synthesizes* a general 3-D model from the contributions of all trades, *inspects* it with the aid of automated clash-detection software tools, and *presents* it interactively to relevant participants during BIM coordination meetings. These specialists are the navigators to the new trading zones of BIM.

At the TWM project, new forms of specialized work converge in the figure of the BIM coordinator. The coordinator is the figure through which the 3-D world of BIM interfaces with the social world of consultants, contractors, subcontractors and clients. When doing *synthesis*, coordinators collect 3-D models from other organizations, introduce them in the project's central folder structure, translate them into the *Digital Project* format, and create partial models for inspection and assessment. The term "synthesis" highlights the fact that a BIM is not the result a single organization, but of the collective effort of a number of contributing parties[421]. The production of this collective model requires considerable effort in terms of the collection of data, the translation between different information formats and standards, and the inspection of the inconsistencies, clashes, modeling issues, that arise from the juxtaposition of 3-D models. In TWM, members of *Gehry Technologies* and the Q+S described the "combination" of 3-D models as follows:

> There were five main 3D models to be combined: the concrete model (in Revit, by [the concrete subcontractor]). The structural steel model (in Tekla by the [steel subcontractor]), the architectural model containing partition walls, doors and internal windows, false ceiling and floor finishing layers (in Revit, by [the architecture subcontractor]), the MEP model (in Digital Project, by Gehry Technologies under the responsibility of GRMS) and the façade model (was to be

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[420] According to a conversation with architect Christophe Hellio.

[421] Seen from this perspective, BIM helps make explicit the collective nature of design and construction.

> delivered by the façade subcontractor, but later on it was decided that the coordination with the façade would be in 2D).[422]

When doing *clash-detection*, a BIM coordinator uses *Digital Project* to inspect the model for potential conflicts between the different models. Part of this process is automated —the software provides an automated clash-detection function that evaluates two sets of geometric elements for collisions. The process, as typically done at *Gehry Technologies* by BIM coordinators, involves loading in *Digital Project* a partial model synthesizing the latest contributions of all trades to the area of interest, and evaluating the combined model for conflicts. This evaluation is sometimes aided by collision-detection algorithms capable of yielding an extensive list of clashes between two sets of geometric elements. However, some coordinators dislike this option, as it tends to yield too many clashes. For instance Lorraine, an architect and a senior BIM coordinator, never uses it "unless I'm doing MEP and steel."[423] She believes the automatic clash-detection command returns "too much stuff,"[424] and many of the problems it reports can be just "modeling" problems (for her, architectural training is crucial to discern the real from the fake conflicts detected by the software). By contrast, Omar Fahmi —an expert user of *Digital Project* and the man in charge of training new coordinators— emphasizes the importance of the automated command to the new hires[425]. While Fahmi builds his role as a BIM consultant as a technical virtuouso, Lorraine —a more experienced architect— emphasizes the advantages that her architectural training and experience represent for coordination.

During meetings, the BIM coordinator steers the camera to show the series of conflicts. A skilled coordinator will steer the camera object of the 3-D environment (*Digital Project*) smoothly from issue to issue, using semi-automated navigation tools provided by the software.[426] A less experienced one will take a longer time in reaching the precise spot where the problem is. As *navigators,* BIM coordinators move across the virtual space of the model to show participants of the meeting the conflicts of interest. When navigating the model, BIM coordinators walk a thin line between speed and clarity. Participants of a meeting may get lost or be confused if the model moves too quickly across the space, or become distracted or impatient if it takes too much time to cut a section, illustrate an issue from a particular angle, or make a measurement between two elements. Depending on how skilled the coordinator is with the software, he or she may be able to accomplish other tasks besides the navigation and accounting of the conflicts. These

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[422] Chris Reinig and Patrik Pynaert, "Cleveland Clinic Abu Dhabi Case Study", 2010.
[423] From a personal conversation.
[424] Ibid.
[425] It is easier, after all, to teach how to run a command than to teach when a duct's proximity to a column may represent a problem.
[426] Typically, in preparation for a coordination meeting, BIM *coordinators* spend hours marking the issues and creating paths through the model to organize and pace the meeting.

can include using software features to cut and move sections of the model to illustrate particular conflicts in more detail —generally by request of a participant in the meeting. Also, sketching 3-D objects to test a design hypothesis on the fly.[427]

A disastrous coordination meeting

Coordination meetings are real-time cinematic experiences, paced by the conflicts that the coordinator finds and reports, and by her style as a *navigator*. The BIM coordinators' control of the model, gives them a privileged rights to structure, organize, and pace a meeting. Jacques E. Guillot[428] is an experienced engineer in his late forties who works as a site-manager for the construction of the TWM. He's skeptical of technology, and refers to BIM meetings sarcastically, as "BIM shows."

In one of his first encounters with BIM in a coordination meeting, Guillot pointed at the model projected in the wall and said "this 3-D model is nice, I'm impressed, but it's *this* what we are building." With the utterance of the word *this* Guillot hit the table on a stack of plotted *AutoCAD* drawings issued for construction by the architect. Given the context —a builder's coordination meeting— the adjective "nice," used by the project manager engineer, had a poisonously pejorative connotation: it underlined Guillot's skepticism about BIM's status as a reliable source of construction information. Moreover, it revealed his understanding of BIM models as *renderings*, akin to those made by architects to represent the spatial qualities of a project —images without any claims to material or structural rigor. Guillot continued, to the chagrin of the participants, furthering his view of BIM coordination as a corrupting force in the project:

> I'm used to sitting in a room with the decision makers, each one with their own set of drawings, and together discuss and figure out solutions for the issues. Instead I have you [referring to a confused audience of task-force managers and "overseers"] and a couple of IT guys [referring to the two BIM coordinators in the scene].

Talking to the BIM coordinators in a defying tone, Guillot added: "If *you* have more updated information than *I* do about the project maybe *you* should be the project manager." Guillot's reactions deserve special analysis, as illustrations of a typical form of resistance against BIM.

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[427] In a coordination meeting, for instance, it became clear that the space provided by the *IFC* architectural drawings in an auditorium was insufficient for allocating a large mechanical ventilation unit. In collaboration with the MEP specialist and a consultant, the BIM coordinator tried to, first, relocate the 3-D element in another part of the building, and then, was asked by the consultant to create a 3-D element with different dimensions in order to be able to locate the unit in another available space.

[428] I use a pseudonym to protect the anonymity of the subject.

An important element of Guillot's frustration with BIM is what he perceives as an increased physical, cognitive, and organizational distance between him and the project's information. He is used to the paper-based coordination process, where incumbents of all trades negotiate responsibility in both design and construction by marking solutions directly on paper (he is, in fact, known for the quality of his hand drawings). BIM, in contrast, requires for its operation of specialists capable of "driving" the 3-D model, cut precise sections in a few seconds, and sketch 3-D objects to test design hypothesis on the fly. Faced with the projection of a 3-D model in a software system he doesn't know how to control, and operated by a new actor playing the role of "navigator," Guillot's reaction is anxious and defensive. The control has been, quite literally, taken *out of his hands*.[429]

David Mindell has observed how Lewis Mumford understands technology through the concepts of separation, dissociation and divorce, enabled by different forms of technical practice."[430] Besides the the distance introduced between him and the project's information by the model, Guillot is frustrated by an increased organizational distance between the conflict's identification and its solution. In an interview months after the meeting, Guillot explains why the channels of verification and approval of BIM constitute an unnerving bureaucratic overhead on the project [Figure 41].

> [In a BIM meeting] it always ends up in "we will check" or "we will send you an email" and then [the report is] sent to five different persons and they all have to say nay or yay, and there's always someone who comments, or who leaves the back door open...

Without the client's enforcement of BIM on all teams, Guillot recalls, the project's managers would've trashed it at the beginning of the project. However, Guillot admits that his frustration tempered when he started seeing BIM as a reference to the team. In an interview at the final stages of the construction, Guillot admitted "now that the BIM is behind us, BIM has become more popular." Guillot celebrated its role as a medium to reference the actions on site *a posteriori*. As a non-prescriptive, superseded recording

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[429] While the meeting was disastrous, many others were not. I present Guillot's views as an example of the arguments drawn by skeptics about BIM, and as a form of explaining aspects of the coordination process. After participating and conducting dozens of BIM meetings (as a BIM coordinator) I observed that the most successful BIM sessions are those that don't leave all to the model, but those in which participants engage different media, and go back and forth between the projection and the documents on the table. Combining BIM inspections with drawings and models, and laser-pointers with color markers, gives a sense of familiarity, and enhances the shared space in which coordination takes place.

[430] The printing press is near the top of the list: "Writing was the key technology in this evolution, and for Mumford (as for many others) the printing press served as the prime example, effecting 'the divorce between print and firsthand experience' by allowing texts to travel great distances from their origins. David A. Mindell, *Between Human and Machine: Feedback, Control, and Computing Before Cybernetics* (The Johns Hopkins University Press, 2002), 3. Bruno Latour elaborates this theme in Latour, "Visualisation and Cognition: Drawing Things Together."

instrument. As a reference tool "behind us." This "behindness" will be further analyzed below. I now turn to discuss BIM's aspiration to become a common language for design and construction.

A "Babel Tower"

The metaphorical constitution of BIM as a *lingua franca* for design and construction acquires a special meaning in the ethnically and nationally diverse context of the TWM project. In addition to the diversity of cultures of representation and work, *Gehry Technologies*'s managerial role was made more difficult by linguistic barriers across the workforce. Among white[431] consultants and engineers, it was a cliché to describe the "multi-cultural[432]" crew of subcontractors and laborers involved in the project as a "Babel tower." This is captured perfectly in the relationship between the BIM provider *Gehry Technologies* and the local Mechanical, Engineering and Plumbing (MEP) subcontractor company GRMS (Gulf Region Mechanical Services). At the beginning of the project it was agreed that *Gehry Technologies* would be responsible for training and managing GRMS personnel in the production of a BIM-grade 3-D model of the MEP services.[433] In the following excerpt, Evan Del Bosco,[434] a *Gehry Technologies* BIM Manager, discusses the difficulties of getting the Hindi and Urdu speaking team of GRMS to abide by *Gehry Technologies*'s protocols of information production and exchange.

> Most of them [GRMS employees] were fresh from India... I mean, they have diplomas and stuff, but when it comes to English ... [in the project] all the communication and everything is done in English, it's not like we're doing it in Hindi. I'd say the [GRMS] company is about 95% Indian, and I'll say they do everything else in their language... Even to the point [that] when we are having a conversation... a coordination meeting, I speak English, a colleague of mine from Gehry Technologies would speak English, but I'd say there's about 10 people from GRMS who all speak Hindi, and their local you know [languages]. When it comes to discuss something with you I speak English and they speak English to me but... when it comes to a general discussion with the 10 people in the room and 2 people from Gehry Technologies singled out... they discuss everything that they're talking about in their own local language! Which I'm supposed to understand, so I'm lost! I have to always stress the fact that "dude, there's a guy here who speaks English and doesn't speak Hindi" and there's a lot of time wasted over there because you have to try and repeat the whole thing again, which...

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[431] I use "white" to refer to subjects educated within the Euro-American system, regardless of ethnicity.

[432] If in the world of New York hair-dressing saloons "European" is mostly an "euphemism" for Polish or Eastern European, in Abu Dhabi "Multi-cultural" is mostly an euphemism for South Asian.

[433] Because of the sheer complexity of the Mall's MEP services, the task of producing the construction drawings of the Mechanical, Engineering and Plumbing services' drawings concentrated most of the difficulty in an otherwise fairly conventional —if large— project.

[434] I use a pseudonym to protect the anonymity of the subject.

> Because they're not very familiar with the English, you know sentences and everything; they even miss out a few of the important points when they try… to translate it into English.

In the following excerpt Del Bosco speaks of "scripting" the GRMS team's actions by means of graphical and "sign" languages, creating ad-hoc languages for management on the spot.

> In order for me to manage their team, the… I would say… the Hindi team… Used to be able to like you know... It's just like sign languages: I had to really tune my ears and my eyes very well and make sure I drafted out like… simple instructions for these guys to work with, so there are times when I, I can… I could be able to even close my eyes… and say, this is what he's done and this is what he's going to bring to me because I have given them simple instructions, I've been able to like, like… script it! I would script it out the whole you know, scenes for them to follow, in a movie, which they have to do, almost every day. And with time they became very used to those processes…

Not-so-perfect slaves

The GRMS offices are in a "barrack" complex neighboring Q+S's. The space where the GRMS modeling team works is a small, noisy room, crammed with South Asian men in their early-to-mid twenties. They work with laptops loaded with *AutoCAD* and (a few) *Digital Project* software. Day after day, their work is to model the mechanical guts of the TWM: an impossibly intricate network of ducts, pipes, shafts, risers, booms, ventilation units, water risers, sum pits and floor drains essential to the building's functioning. Between 12 and 15 modelers usually share the space, of around 150 square feet, working frantically, talking loudly, elbow with elbow. Two air conditioning units roar, adding to the noise, but are far from bringing the space's temperature down to a comfortable level, and thus the air feels thick. The blinds in the two small windows are usually semi-closed, adding twilight to the heavy atmosphere. Most of the modelers are Indian, some Pakistani or Bangladeshi. A number of older employees —MEP managers from GRMS, mostly South Asian— circle around the narrow space left by the desks piled against the walls, nervously, with calculators, cell phones, and paper drawings. It's common to see them (almost literally) on a modeler's back, shouting instructions about where to place a duct, how to avoid a clash, or what the dimension of a sump pit should be.

Because the production of the construction drawings was always behind schedule, GRMS employees are under unreasonable pressure from their GRMS managers, who are, in turn, under unreasonable pressure from the Q+S (authority cascades down directly from the client in the project's vertical hierarchy). The MEP modelers are thus forced to work longer hours than other subcontractors, commonly until ten in the night during six —often seven— days a week. Unable to obtain driver licenses

—because of lack of contractual privileges— the modelers are picked up by a bus hired by their company to take them back to their lodgings at a nearby camp. This is not the collaborative complex Negroponte imagined as the future of human-machine creativity. There is no glamour here. Nor are the machines the perfect slaves Coons imagined, releasing people from labor. There is no leisure here. These men-machine assemblages offer a dystopian glimpse to the reality of contemporary design and construction: the digital proletariat of MEP modeling and coordination in the TWM.

Adaptation and resistance

Del Bosco occupies a small desk in the room. He has worked for 15 months with the GRMS team, struggling to produce 3-D models for the Q+S's approval. Sometimes training, sometimes managing, sometimes doing modeling himself, Del Bosco's skin has become thick —and he often says with some pride. His role is to make sure that coordinated construction drawings can be derived from the models he and his team produce. This involves a constant "fight" against the GRMS's well engrained culture of 2-D coordination.

> It's been very, very difficult, for the past year and three months ... [to be] working with GRMS. It's been very, very difficult. Some of them are very primitive, and very traditional, "minor" oriented...[435] As of today, we still have problems because they still think like, 40 years, or 10 years ago, you know? 2D coordination! The major problem I've had as managing the team was... [that] they have a huge team for the combined services drawing production. That is what goes to site as final drawings for installation. And... the manager [who] carries on his duties on that team is a very old guy and he's not like, very at ease with modern technology. So he even calls us that we are playing a "BIM monopoly." So, imagine working with such a person... You end up, at the end of the day, with the same results. It's a very, very difficult thing. You almost have to fight, like, almost every day, to make them understand. It's the only way. Because the drawings get to site, and the drawings are different from what we have in the BIM model. It's because they focus so much in doing the 2D drawing on their own, and not consulting the BIM team [or the] BIM departments. But the funny thing is [that] they have [assigned] coordinators, from their own team, to help us coordinate the BIM model.

A strict schedule of weekly submissions requires Del Bosco to submit a new coordinated portion of the model to the Q+S through the shared folders set up in the internal network. The submitted portion of the model is then downloaded, translated into the IFC format, and incorporated into the BIM model by the

---

[435] He means they behave like kids sometimes. An ethnography of immigrant men in these contexts is overdue. For a literary account, see (Tr.), *Goat Days*.

team of BIM coordinators working directly for the Q+S. Once incorporated, the model is inspected for clashes, and a report detailing the conflicts is produced. Then, a coordination meeting between members of the relevant trades takes place to find solutions to the conflicts. The synthesis and clash detection process by the BIM team at the Q+S demands that the model is "frozen" for a day or two before the coordination meeting while the clash-report is produced. This plan, however, proved ineffective given the frantic demands for more and better coordinated drawings by the installation teams on site. GRMS was forced to continue working on the submitted areas until the coordination meeting, and to resort to their good-old "artisanal" coordination methods.

The solipsistic turn of the coordination process led BIM coordinators, to their frustration, to knowingly inspect and report on models that were outdated by the time their report was complete.

The para-coordination paradox

At GRMS, older managers didn't "buy into" the BIM process, and continued to rely on 2-D coordination media and methods. However, the forms were kept, and the teams continued to send weekly models, and attending the meetings, to abide by the client's directive of using BIM. When I asked him about the process of instructing GRMS managers about BIM, Del Bosco laughed softly, and explained that

> Well, that hasn't been easier at all to do. From time to time we organize seminars for them, especially if they're top managers. They don't directly get involved in the coordination. They sit up there and tell their subordinates as to what to do. As to how the whole thing comes out, they really don't put so much time into it. All what they want to hear is that it's done and that it's submitted.

Without strong internal leadership, the teams quickly resorted to their traditional coordination system when pressure started to mount. To comply with the frantic project schedule, GRMS established a coordination process parallel to, and different from, the BIM coordination. In the following excerpt Del Bosco admits how BIM coordination was concurrent with other coordination processes.

> Since what happened … [a major delay], having to deal with the 2D and the 3D at the same time there was a little bit of a delay… on the part of coordination because they were new to the whole process, and their managers were like… shouting all the time, so they enforced to do the 2D drawings at the same time when the 3D coordination was happening…

The failure of the *plan* to prescribe *action* is illustrated by the fact that the drawings produced for the Mechanical, Engineering and Plumbing services (MEP) company (GRMS) for construction were produced outside the BIM workflow. Moreover, by how BIM coordination was ultimately outpaced by the parallel processes of "artisanal" coordination by the GRMS teams:

> EB: ...The 3D coordination was happening and the 2-D coordination was going ahead because they had to do submissions.
>
> DC: And they were kind of parallel no? They were not... Or were... Were they connected? The 2-D and the 3-D?
>
> EB: We tried to strategize to have them on parallel, like... but along the lines they had to move much faster than how the 3D coordination was happening, because [we] spent so much time in the 2-D, and the same guys who were supposed to do the 3-D coordination were the guys doing the 2-D, so we are getting very little information to put in the 3-D to get it out.
>
> DC: So do you think that part of the effort of the 3D coordination was... lost because of that kind of separation between the 2D coordination and the 3D coordination?
>
> EB: Yeah well, I would say that. From the beginning it was a little lost because the same guys who were supposed to help us with the BIM 3-D coordination, were the same guys who were policing the 2-D drawings. So we were in a way forced to be able to catch up with the whole project timeline, were forced to take some of these 2-D coordination things that they were doing, back into the BIM model, and fix those errors. Because at the end of the day the 2-D drawings go for site construction, and the BIM model has to be there for checking before the construction goes on. So how to make sure that these two things are matching...

The MEP coordination of the TWM project happened, but not in the centrally controlled manner imagined by the flow charts in the documents, but largely through an assemblage of methods that merely (sometimes barely) *included* BIM. The GRMS coordination process shows how the 2-D coordination of GRMS effectively outpaced the process of BIM coordination. Del Bosco and his team of BIM modelers had no choice but to incorporate the results of the 2-D coordination into the model. After all, BIM found its role in the project by becoming a form of "freezing" the coordinated models *after the fact*. By then, BIM had stopped being the central locus of coordination, and had become an extra layer of coordination redundancy.

Interactive data visualization of BIM coordination

The method

In this section I develop new computational methods of observation and analysis to provide a novel perspective into the digital practice of *Building Information Modeling.* I report on an experiment on data collection and visualization of BIM coordination. In preceding sections, I have explored BIM as a social practice. This section seeks to explore its dimension as a flux of information instead. For the experiment, two separate pieces of software were developed. The first was a Microsoft Visual Basic module providing a graphic user interface, filters and functions for representing conflicts in a normalized, object oriented form, as instances of a class. This module was inserted in the Excel coordination logs of a team of four BIM coordinators —who knowingly agreed to the experiment. When using the log, coordinators logged conflicts through the custom user interface provided by the module, storing them in a custom Object class. The second piece of software is a Processing/JAVA application that reads the data yielded by the data-collection module, and produces a visualization of the issues arranged by part of the building, and by responsible organization, through time. The data visualization is an enlivened version of the centralized diagrams discussed in previous chapters. The visualization is arranged as three concentric rings. The first ring displays the organizations, the second displays the project's zones, and the third displays the individual conflicts reported. Lines going from the center to each of the rings interactively display the distribution of issues per organization and zone. Thin lines going from the "zone" ring into the perimeter ring represent conflicts. Each line indexes detailed information about the conflict it represents. A column in the right shows an image of the BIM model, a description, and other detailed information. Using interface controls, a user can interactively change the visualization to display the state of coordination at any date during the period observed. The result is an interactive data visualization displaying the increased complexity of the coordination process in time, as the BIM coordinators identify and report on more design and construction conflicts [Figures 42 and 43].

By tracing the flows of information between different organizations over four months of a project's design and construction, the visualization enlivens the model of centrality with which BIM is often described.[436] By using the flows of digital information as a source of data, this chapter seeks to improve our understanding of the social and technological infrastructures that enable the contemporary production of the built environment.

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[436] See discussion about the central representation of BIM in Chapter 4.

Limitations to the data visualization

The interactive data visualization of BIM coordination is at prototype stage. At its current state of development it has revealed limitations to both the data collection and visualization strategies. For example, during data collection, the team did not record the "closing date" of the conflicts. As a result, once a conflict is reported it remains open until the end. A more accurate representation of the process would graphically distinguish between open and closed conflicts. Nonetheless, the current prototype is effective in displaying the distribution of found conflicts in time, while enriching our understanding of the organizational complexity of BIM coordination in a large project. To address this, future work needs to provide a more complete graphic user interface and data structures in the data collection module, that considers each conflict's "history" as fields.

By working on these limitations, the application can deliver a richer picture of the coordination process.

Conclusions

Ad-hoc infrastructures of resistance

In the projects I observed, these aspirations are contested by the projects' cultural and legal contexts. The empirical observations of the situated practice of *Building Information Modeling* distort the imagined cleanliness, universality and centrality of the model as an infrastructure, and its commonality and transparency as a language. The parallel processes of coordination and work in the design and construction of the Abu Dhabi Thomas Wynne Mall show how competing cultures of representation and work vibrantly contested the centrality of the model at *each and every step*. Members of these cultures made effective their resistance in different ways, sometimes by ignoring, sometimes by superficially abiding to, the disciplining regime of the *Building Information Modeling* coordination process —this was the case with the parallel process of coordination carried out by GRMS managers and modelers in the TWM project. In some cases, the resistance entailed brutal attacks discrediting the project and its members altogether —like engineer Jacques Guillot's.

Plans as prescriptions of *action:* a generative failure?

Moreover, to the frustration of those involved in the synthesis of the digital model, parallel processes of design production and coordination consistently outpaced the currency of BIM. Some of these parallel processes, like GRMS*'s* MEP coordination of the TWM project, followed their own logic, and proved more responsive to the contingency of actions on site. As a result, rather than to prescribe the reality of the project on site, the BIM team's work was, to a large extent, to *keep up* with the facts on the ground. Measured strictly against its stated goals of prescriptiveness, cleanliness, centrality and discipline, the outcome of the BIM coordination of the TWM falls short. However, I want to suggest that the outpacing of the model by the facts on the ground is not entirely a bad thing. Seen by participants as part of a larger ecology of co-existing systems of representation and work, the BIM acquired new connotations for the project participants. Once Guillot, the engineer, started to see the model as a collectively arranged point of reference, as a form of redundancy, and as a *behind us* instrument for recording actions on site, his initial frustrations tempered. The model gained an unexpected form of legitimacy as an instrument for recording, discussing, referencing (not prescribing), the actions on site.

Descriptions of BIM based on the tropes of centrality and universality mistakenly presuppose that BIM coordination will replace established traditions of design and construction. Instead, the reality I observed was much richer: it was a reality of conflict and co-existence[437].

The liturgics of BIM

Many times during the coordination of the TWM *Project*, BIM meetings were celebrated in spite of evidence that project coordination was independent of them. The legitimacy of the model, however, had to be constantly re-asserted among the involved participants —and before the project authorities— to preserve contractual agreements. BIM coordinators would inspect and report conflicts in the models, and issue their reports; subcontractors would be summoned to the BIM room, and all participants would discuss, one by one, the issues reported by the coordinator before the screen. From this perspective, BIM coordination meetings in the TWM project can be understood as *liturgical* celebrations of BIM's own unfulfilled (yet, expected and desired) centrality[438].

Perhaps we need to re-shape our expectations about technology: expect less cleanliness and universality, and articulate technological discourses that allow us to embrace more openly the contingent nature of human practices.

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[437] A body of literature has observed the way in which varied representation media co-exist in design work. See for instance Suchman, L. (2000). Embodied Practices of Engineering Work. *Mind, Culture, and Activity*, *7* (1&2), 4-18. Also: Suchman, L. (2000). Organizing Alignment. *Organization* , 311-327. And Henderson, *On Line and on Paper.*

[438] In Chapter 4 I discussed how the constitution of the design "artifact" by some advocates of BIM, there are certain tropes that, through taboos, have the effect of sacralizing design.

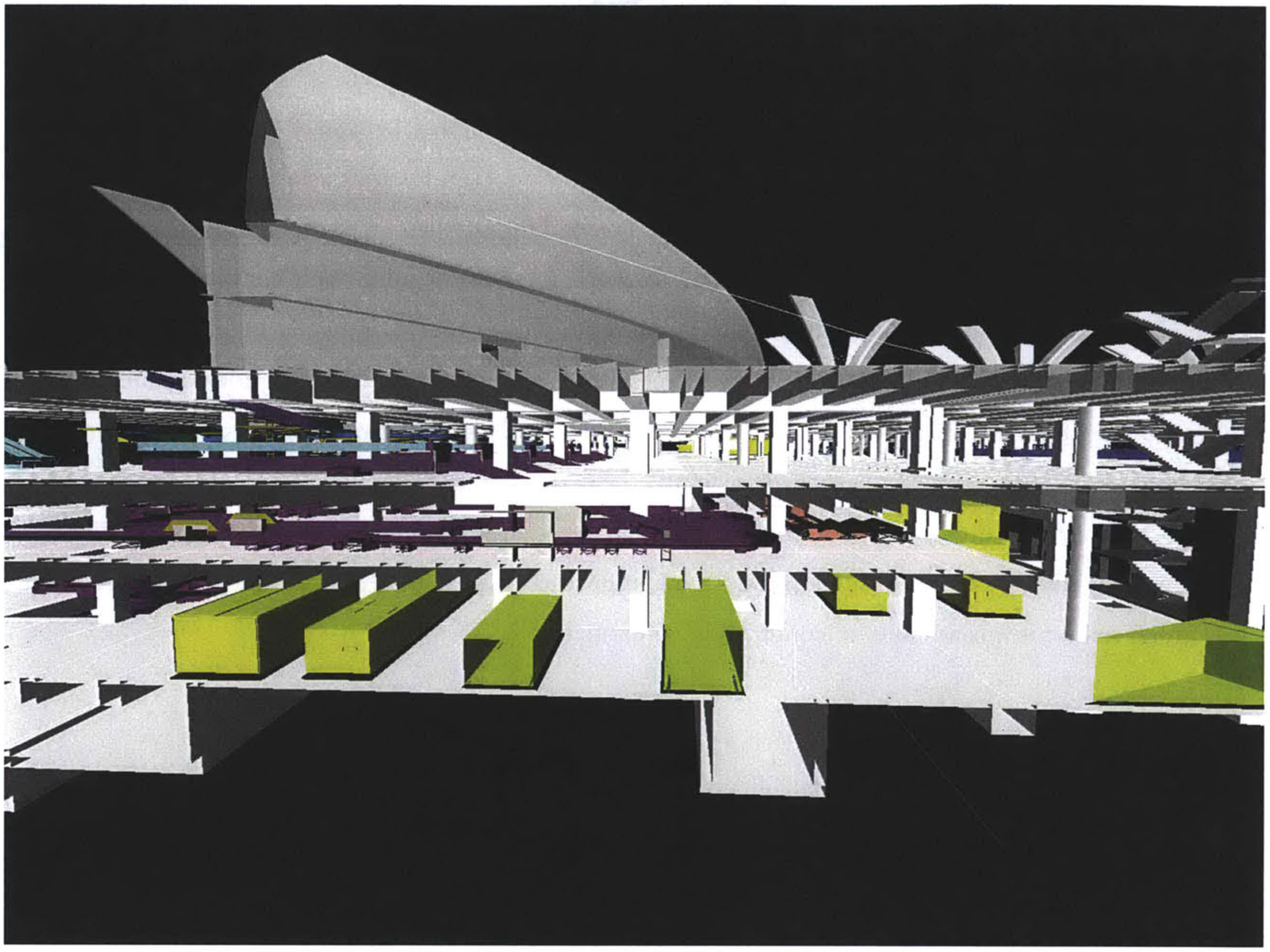


Figure 30. **Example of a Navisworks screenshot.**

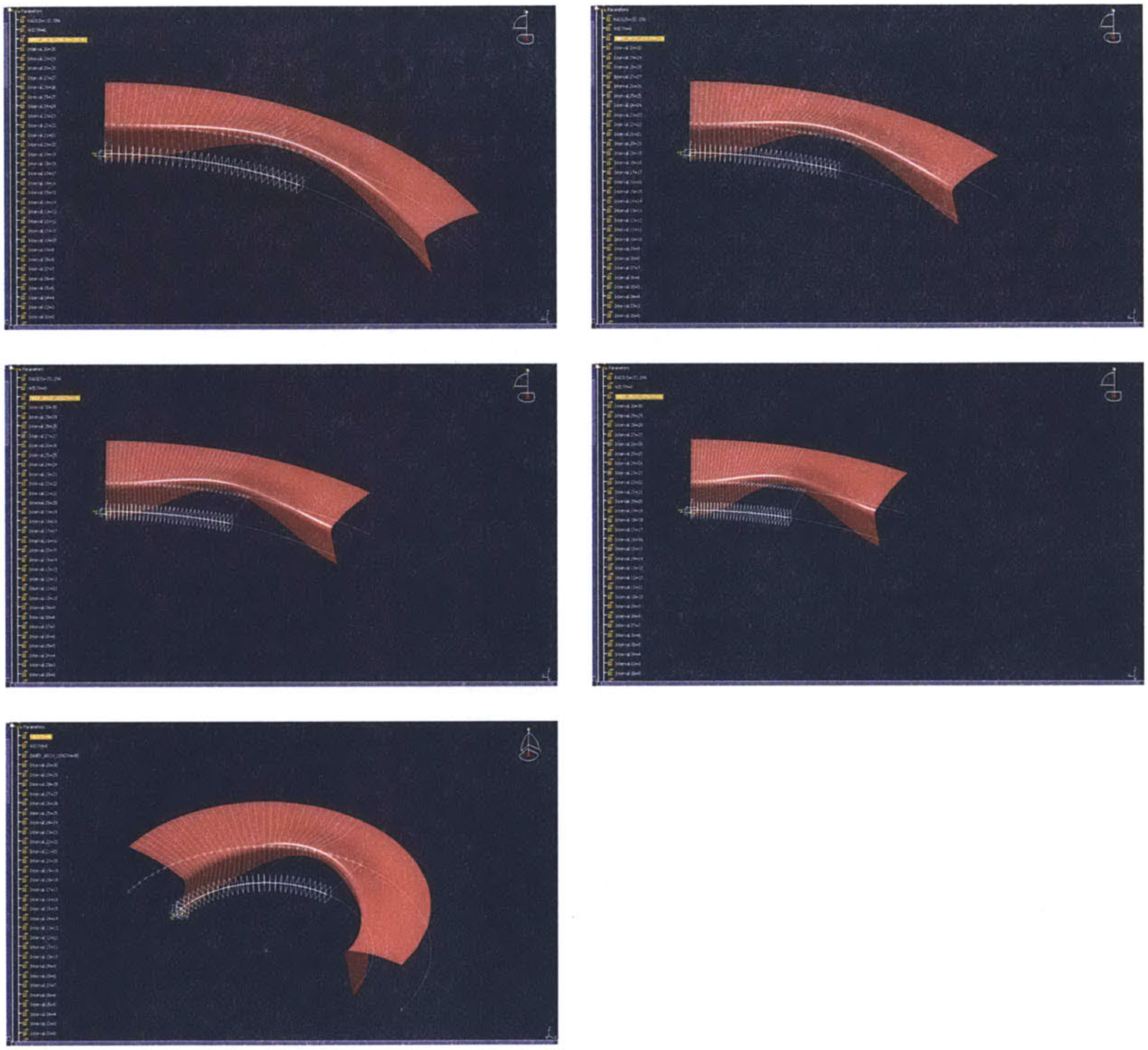


Figure 31. **Flexible modules.**

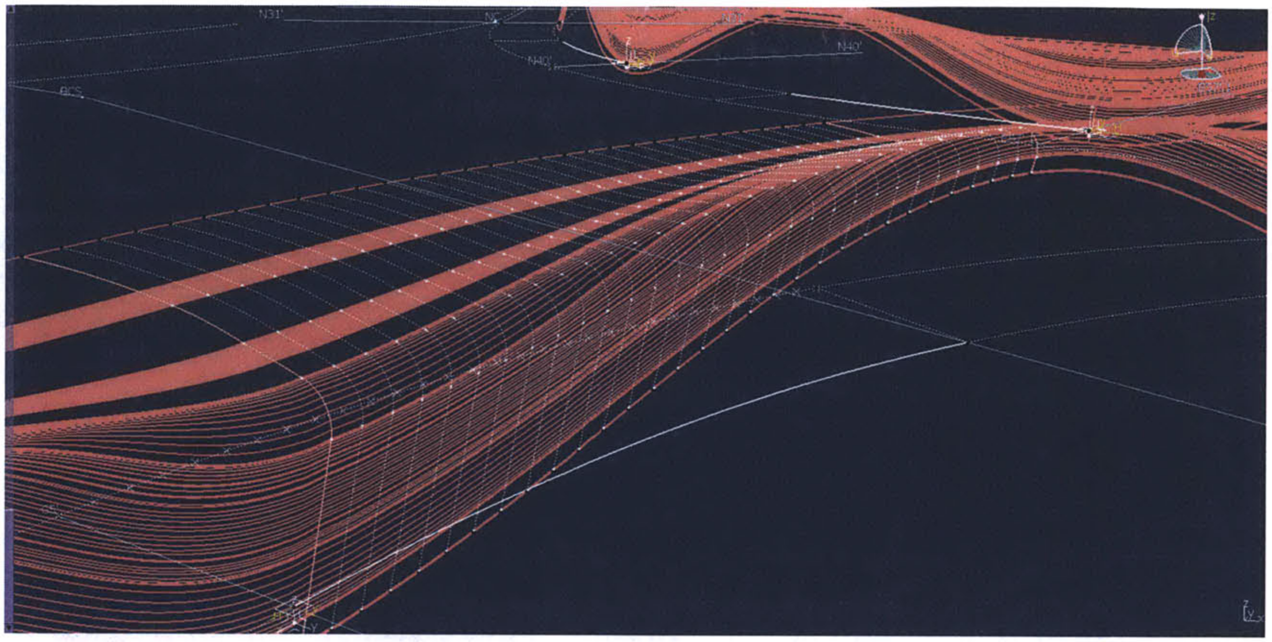


Figure 32. **Image of the first model.**

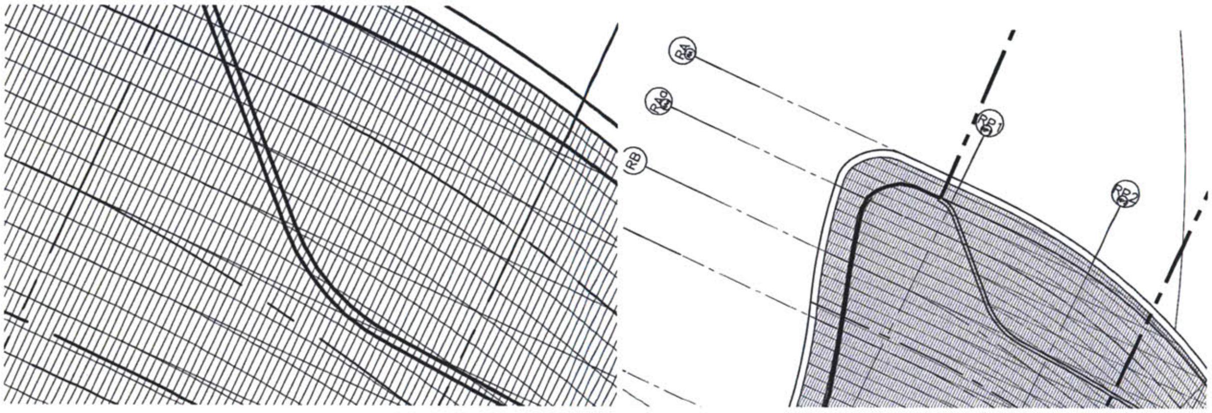


Figure 33. **Details of *IFC* drawing.**

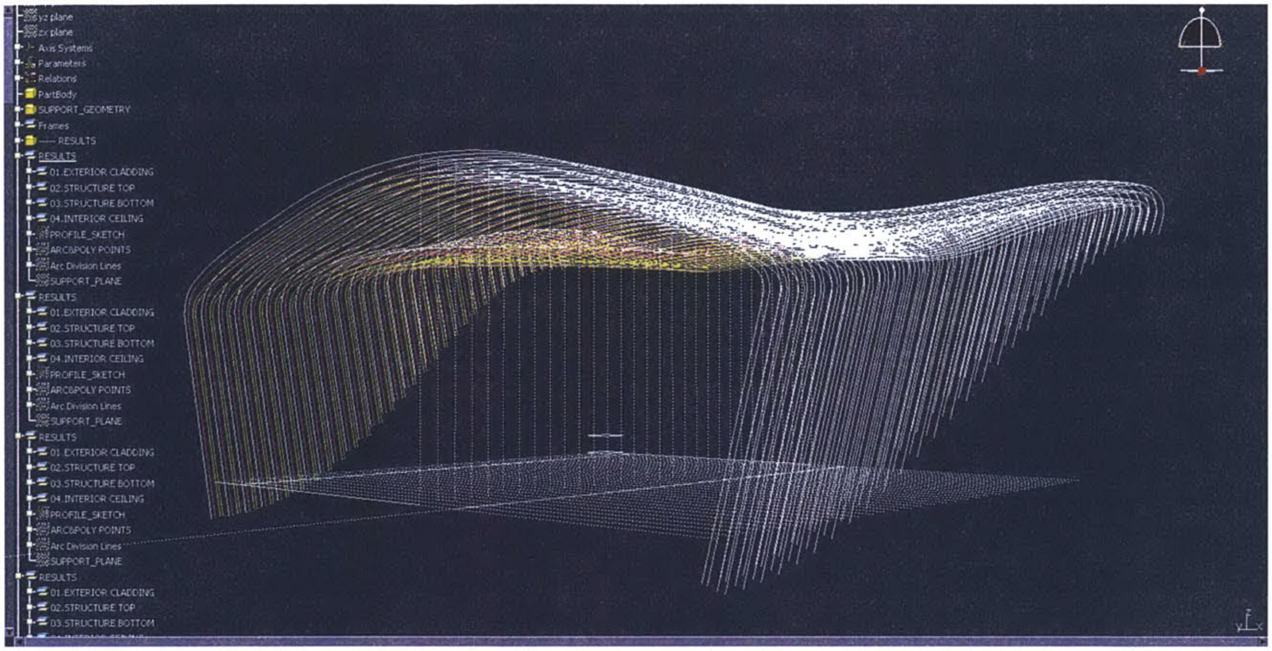


Figure 34. **Image of arcs, instantiated within Digital Project.**

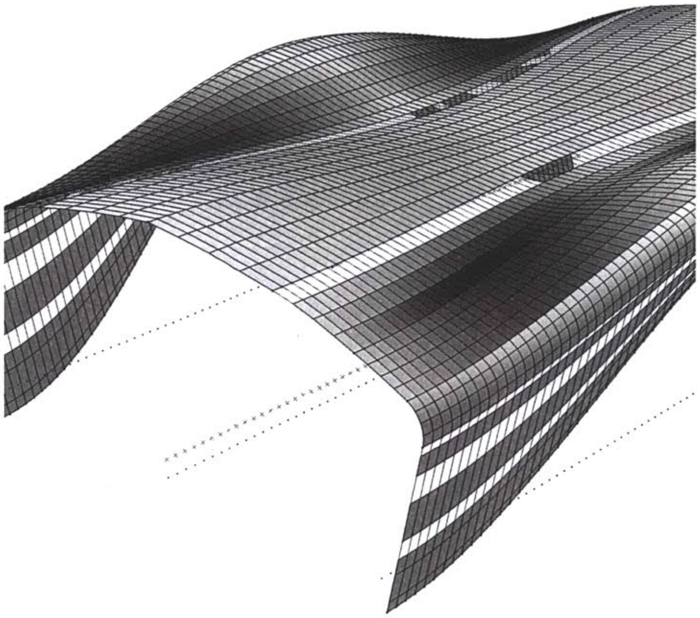
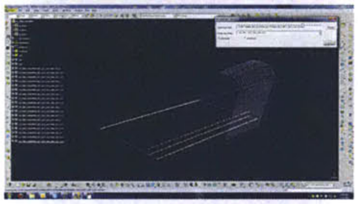
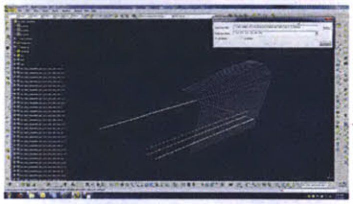
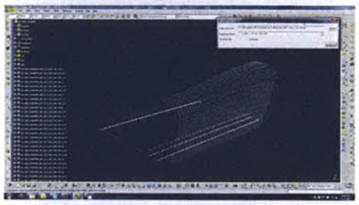
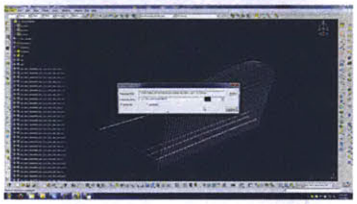
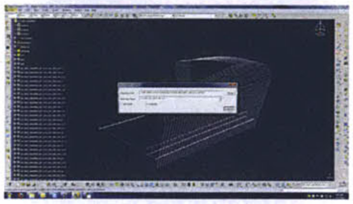
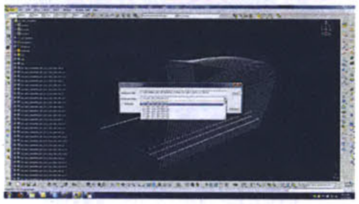
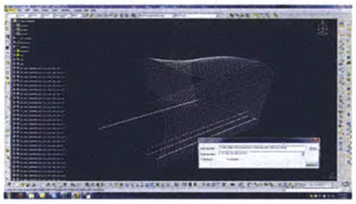
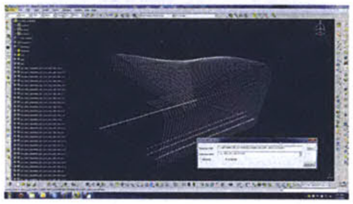
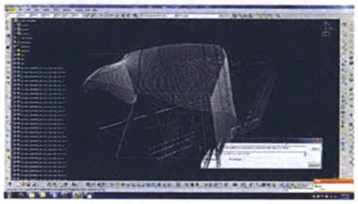
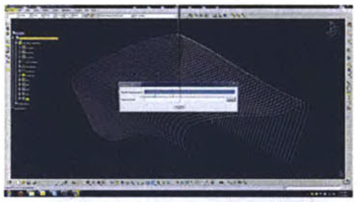
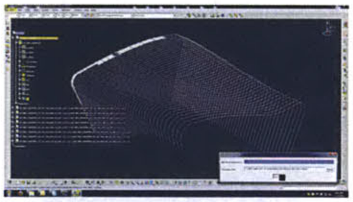
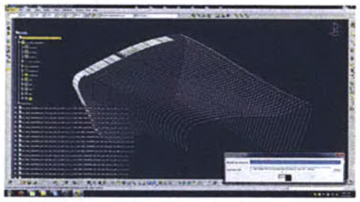
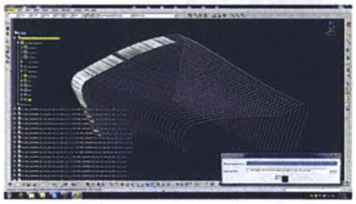
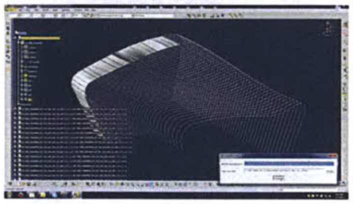
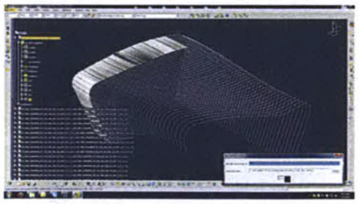
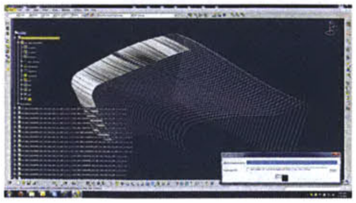
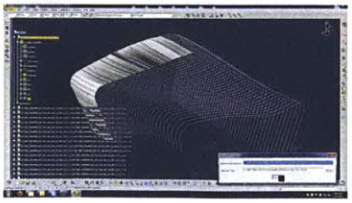
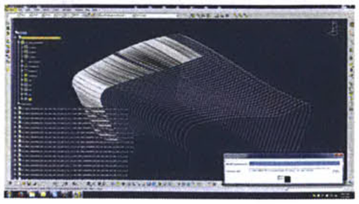


Figure 35. **Image of module with gradient**



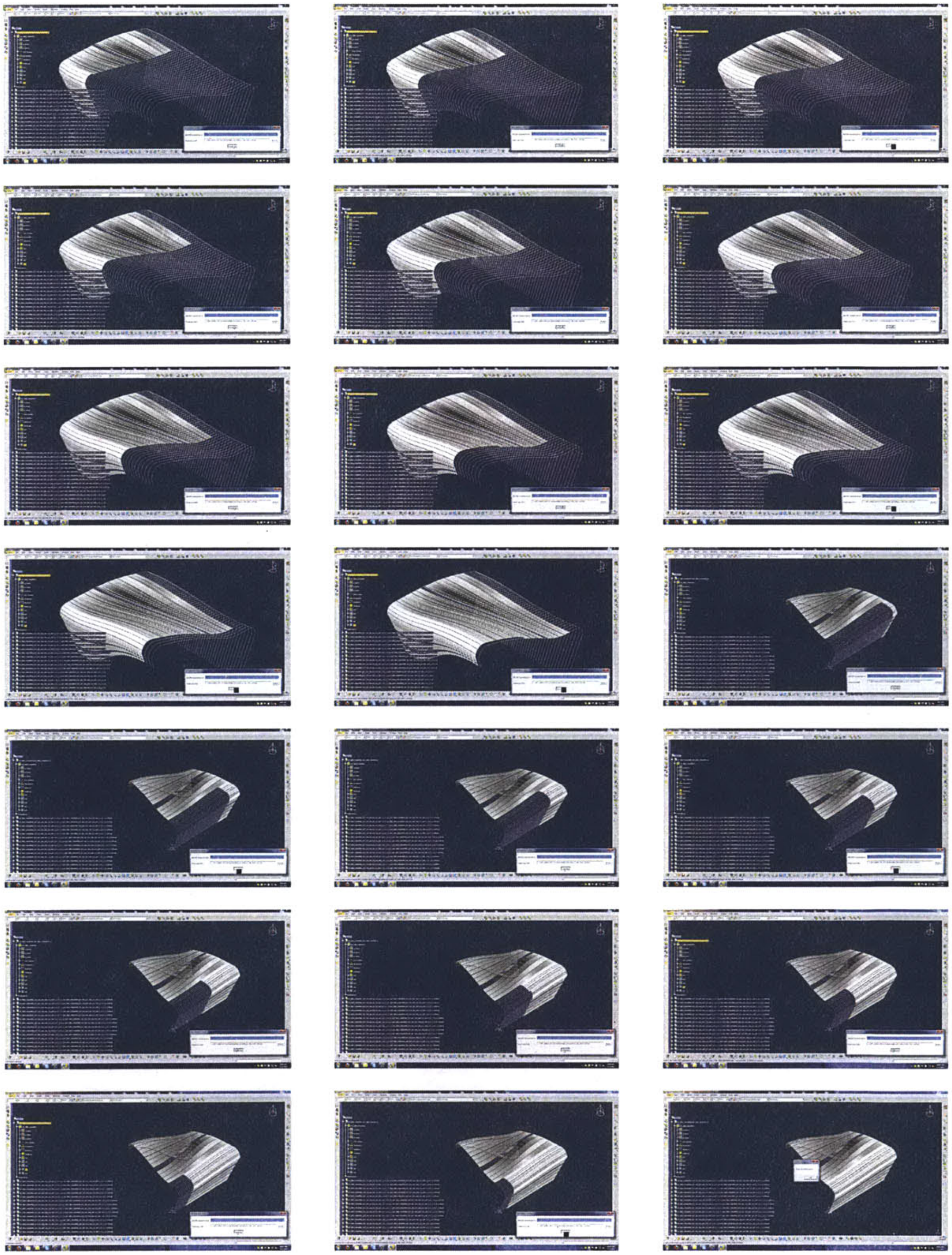


Figure 36. **Sequence of stills from the video**

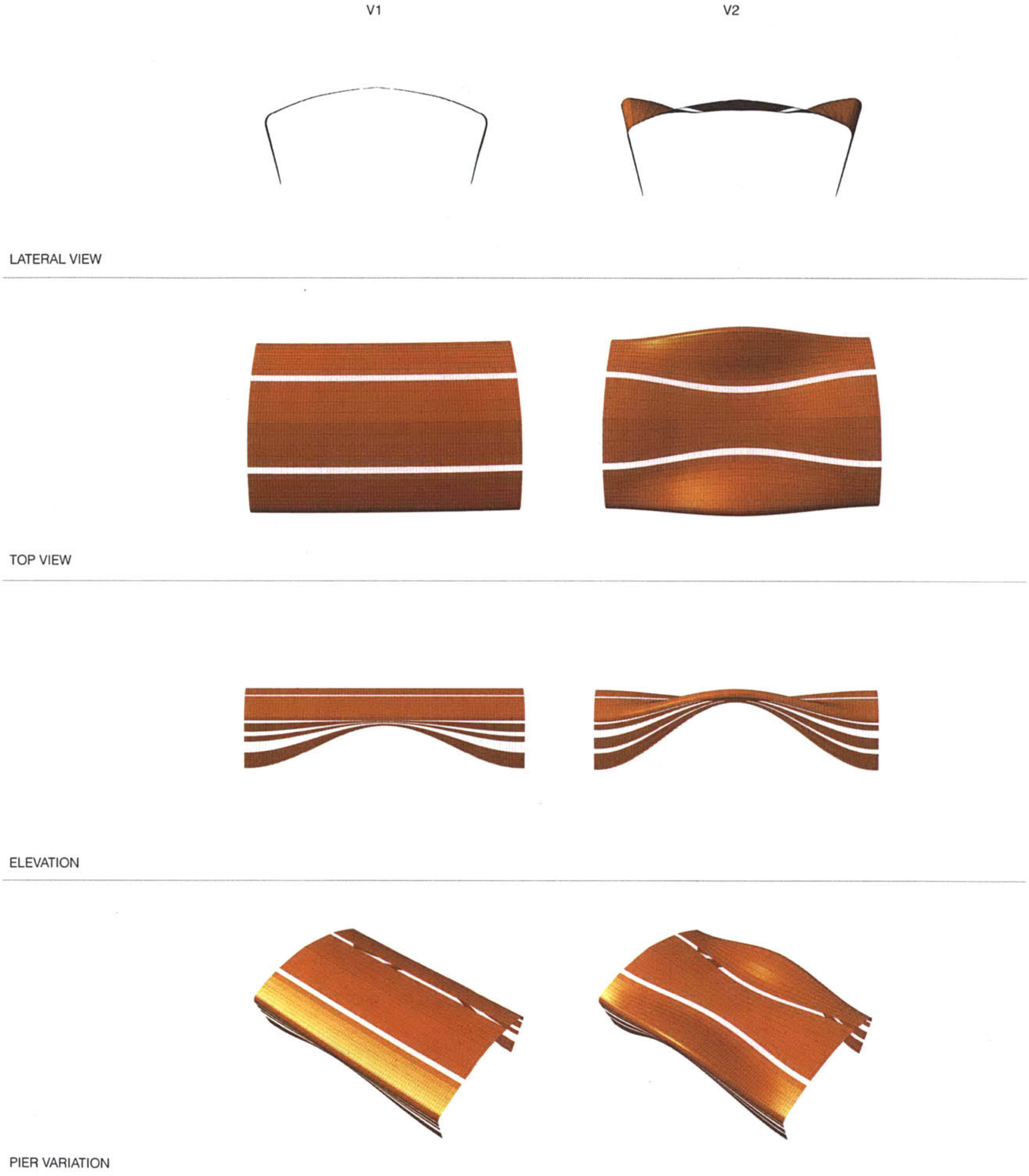


Figure 37. Variations to the exhibition space envelope.

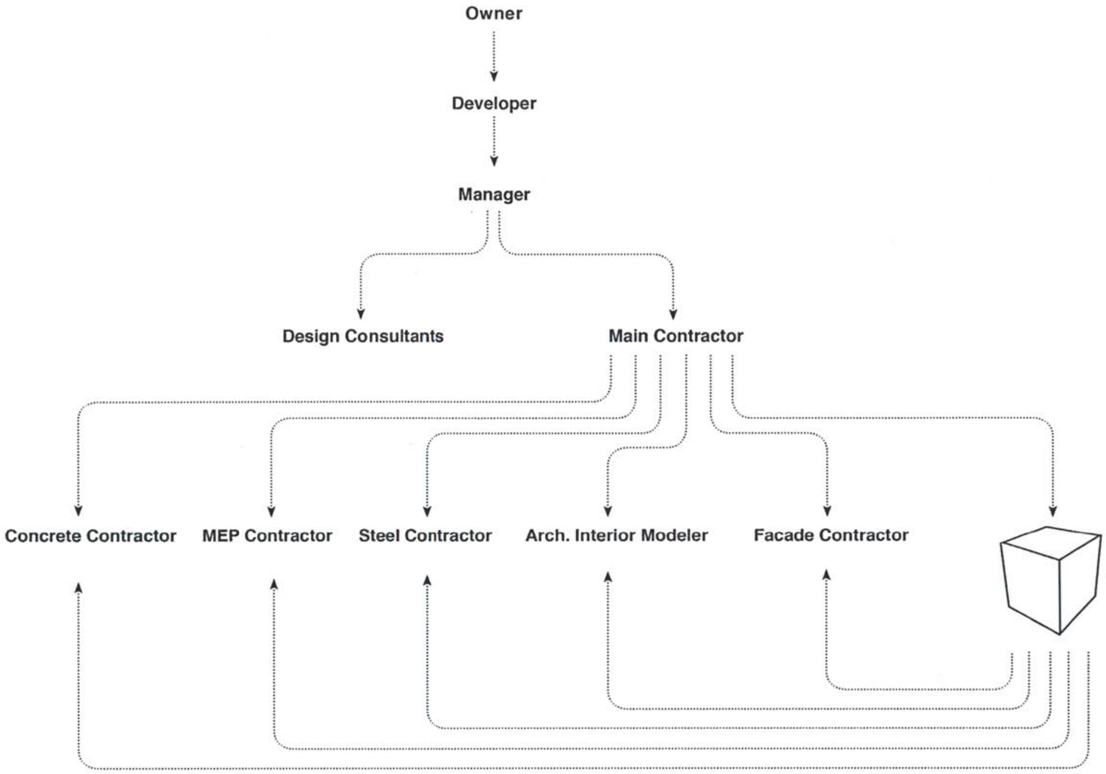


Figure 38. **Diagram of actual TWM organization.**

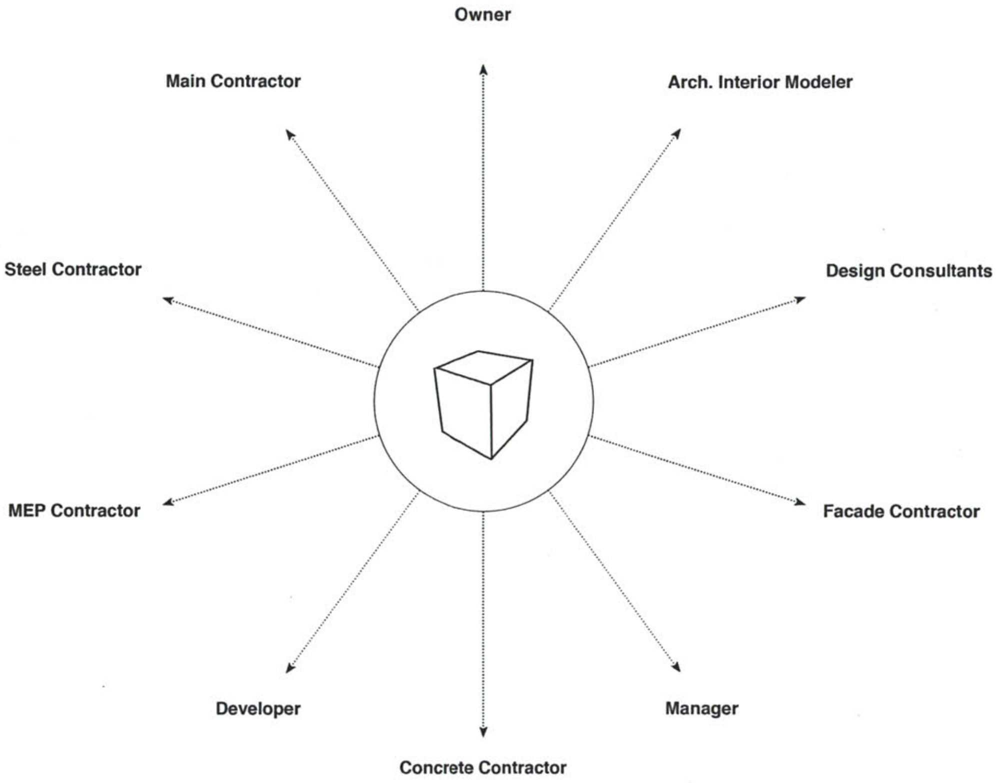


Figure 39. **Central (BIM) diagram of work organization, describing information flows.**

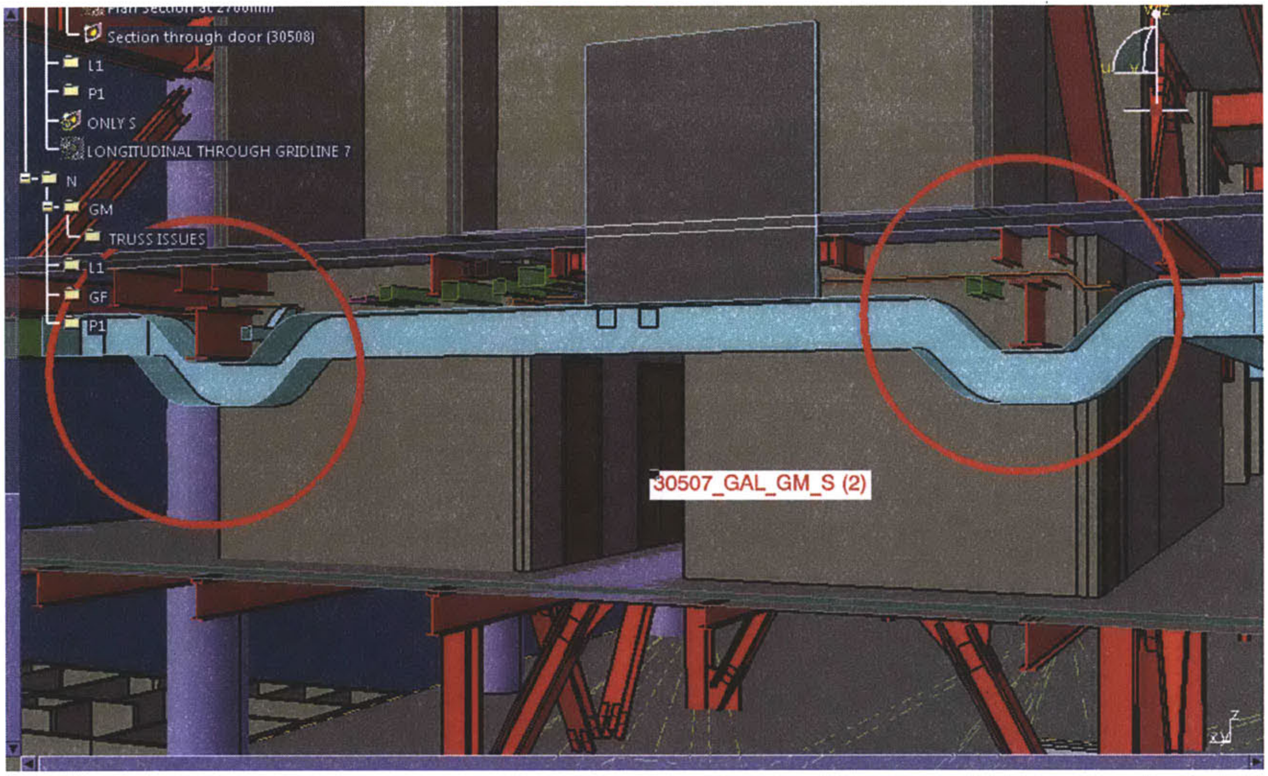


Figure 40. Image of a clash.

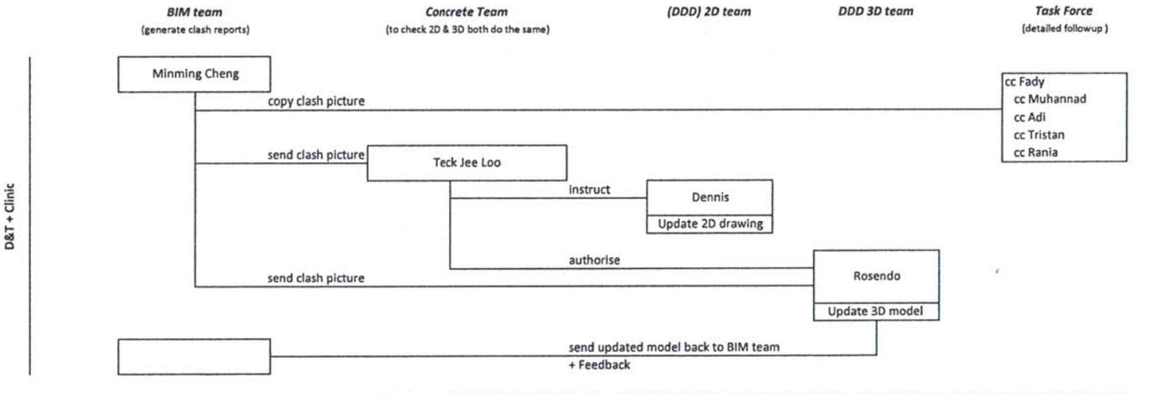


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Figure 41. Diagram prescribing how information about a conflict should flow across actors in the organization.

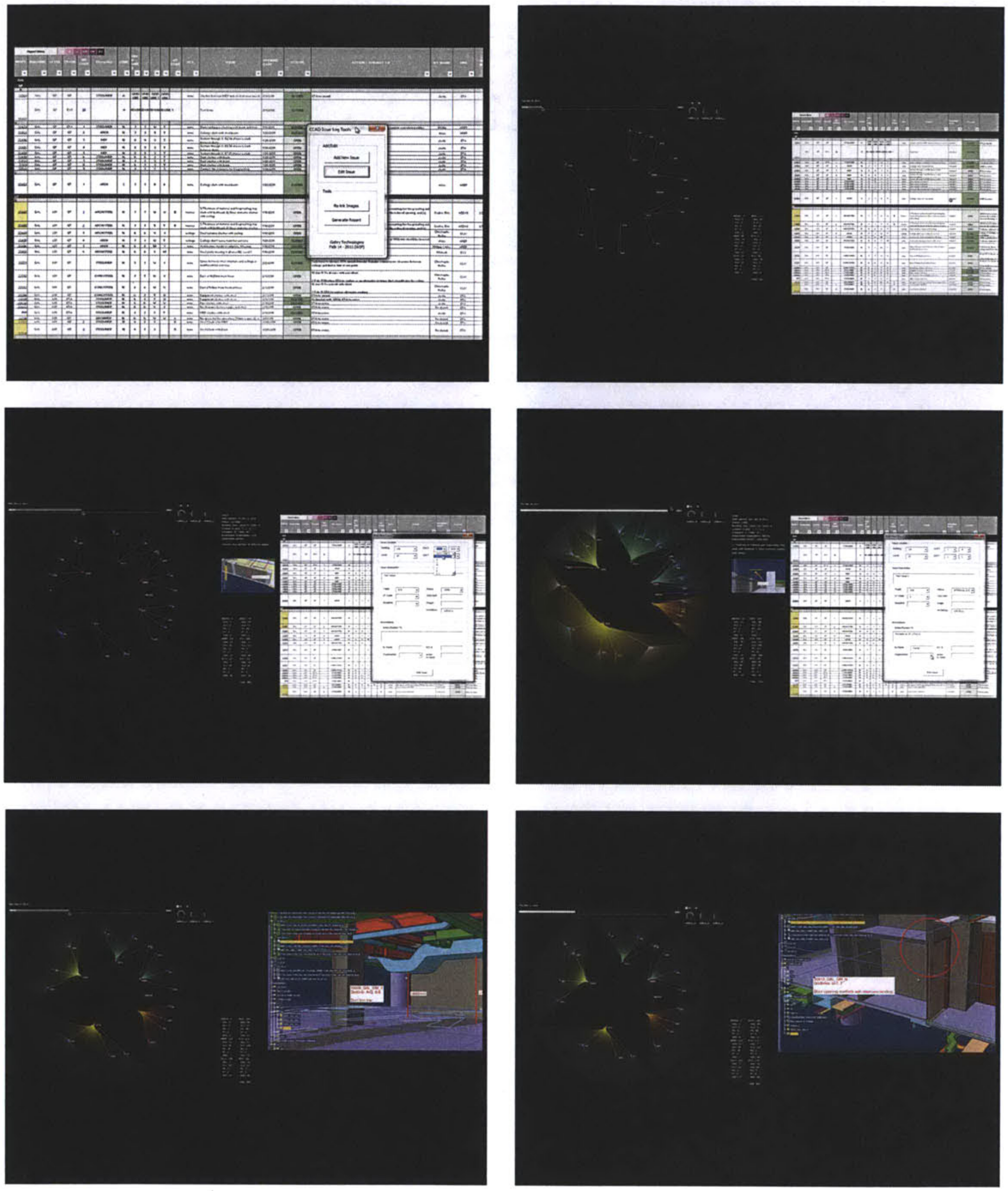
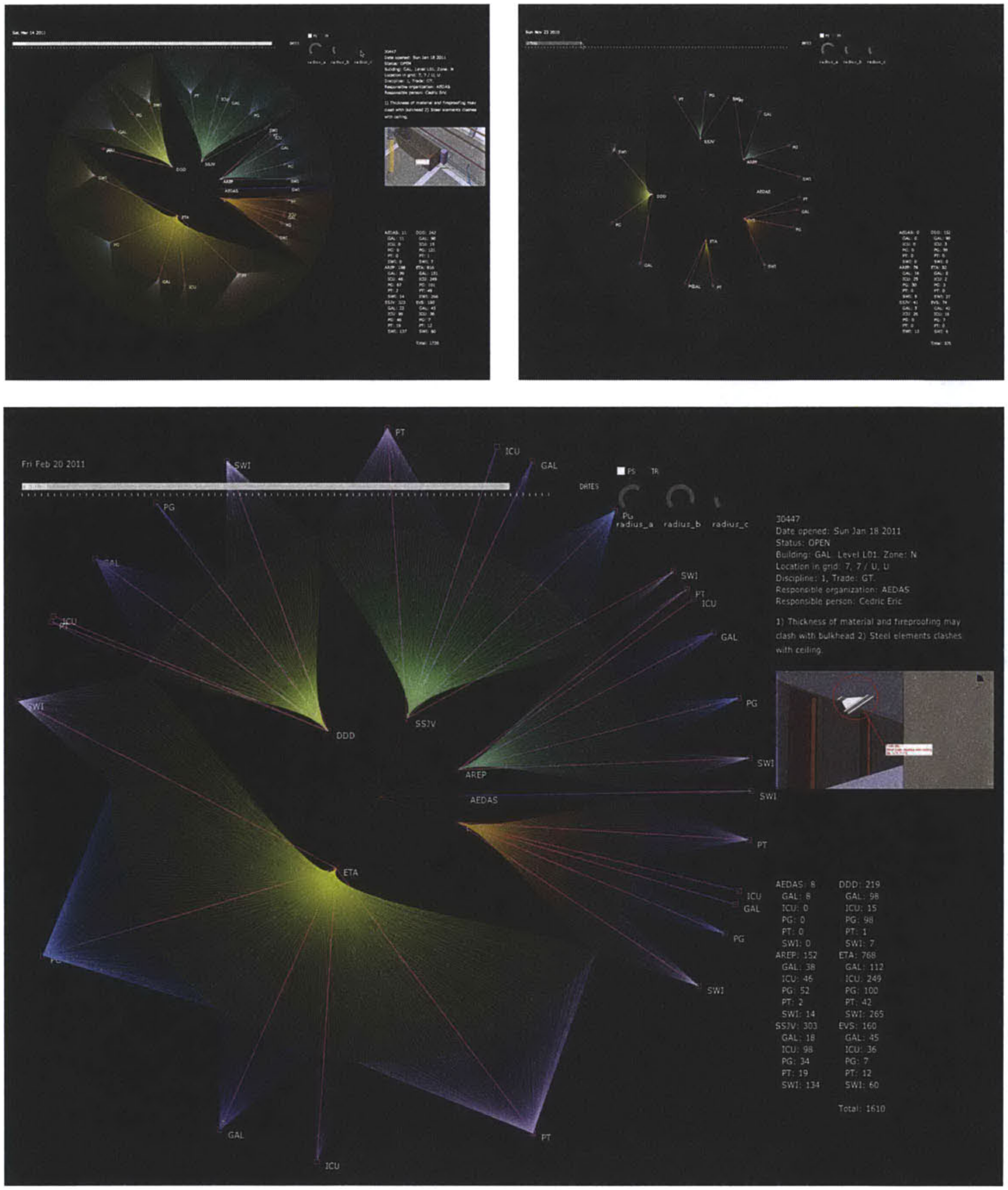


Figure 42. **Stills from a video showing the interactive visualization.**



30447
Date opened: Sun Jan 18 2011
Status: OPEN
Building: GAL. Level L01. Zone: N
Location in grid: 7, 7 / U, U
Discipline: 1, Trade: GT.
Responsible organization: AEDAS
Responsible person: Cedric Eric

1) Thickness of material and fireproofing may clash with bulkhead 2) Steel elements clashes with ceiling.

AEDAS: 8
  GAL: 8
  ICU: 0
  PG: 0
  PT: 0
  SWI: 0
AREP: 152
  GAL: 38
  ICU: 46
  PG: 52
  PT: 2
  SWI: 14
SSJV: 303
  GAL: 18
  ICU: 98
  PG: 34
  PT: 19
  SWI: 134

DDD: 219
  GAL: 98
  ICU: 15
  PG: 98
  PT: 1
  SWI: 7
ETA: 768
  GAL: 112
  ICU: 249
  PG: 100
  PT: 42
  SWI: 265
EVS: 160
  GAL: 45
  ICU: 36
  PG: 7
  PT: 12
  SWI: 60

Total: 1610

Figure 43. **Stills from a video showing the interactive visualization.**

7. CONCLUSIONS

Builders of the vision

In this dissertation, I have identified and documented a "technological imagination of design" emerging around the reconfigured discourses of design and design representation by the culture of technology production in the *Computer-Aided Design Project* —a Cold War era research operation funded by the US Air Force at MIT— tracing it into its contemporary deployment in the technology project known as *Building Information Modeling.*

Exploring the discursive and technological linkages between these two sites, I have outlined the ongoing constitution of technological centrality and universality as dominant tropes in discourses about design production, charting an expanded critical perspective on design that looks at technological systems —such as software— and the cultures that produce them, with their histories and regimes of power, as crucial participants in —rather than as neutral vessels for— the design and production of our built environment.

The dissertation ranges from examining the politics of representation, participation and authorship in the early CAD systems proposed by members of the Computer-Aided Design Project —in particular that in Steven Coons and Nicholas Negroponte's man-machine design systems— to discussing the culture of BIM coordination through an ethnographic portrait —and data-visualization— of its practice at Gehry Technologies in two large projects in the United Arab Emirates.

This study has shown how technological discourses and artifacts act as brokers for culturally dominant conceptions of design, representation, and work.

I have named this study "Builders of the vision" because I found this phrase to say something crucial about the various engineering and design cultures I thread in it. The Renaissance architects and artists who developed the geometric methods for perspective representation, mathematized visual perception and endowed spatial representation with the allure of scientific validity —they built perceptual vision *into* the two-dimensional space of paper and canvas. The MIT engineers, like Larry Roberts, who *hacked into* the mathematics of perspective representation, encoding it in the language of computers, built the foundations of a hybrid representational tradition expressed in the indexical combination of perspective geometry and data —they built the Renaissance vision *into* the symbolic worlds of computational abstraction and its electronic display. The engineers of the *Computer-Aided Design Project*, while computers were still in their infancy, re-imagined conceptions of *design, representation* and *material* in the language, and image, of the computer —they built visionary artifacts, discourses and philosophies of design, casting design as cybernetic systems of information flows (this dissertation showed how the contemporary production of the built environment continues to invoke their vision). The architects, engineers, consultants and laborers working in Abu Dhabi, design and build iconic buildings for the family-state to represent the Emirate as a modern and progressive state —while deleting, in their own transiency, the traces of profound political and ethno-national contradictions. The BIM consultants, working between the dusty construction sites of Abu Dhabi and the sleek virtual environments of *Digital Project*, painstakingly negotiate with sub-contractors and clients the collective construction of gargantuan three-dimensional models enabling them to envision the smallest details of the buildings they produce —they build the urbanist's vision in the abstract world of the computer.

By listening to their voices, this dissertation has sought to enrich our understanding of how engineers, architects and technology advocates have theories, philosophies and forms of understanding that guide —or characterize— their encounters with technology. I hope to have shown that not only their artifacts, but also their voices, have built our contemporary vision and given shape to our world.

Metaphors and geographies: roads, words, centers

In my study, I have identified the metaphors of infrastructure and language —*lingua franca*— and the geographical trope of centrality and periphery, as vehicles to explore the worlds of representation, management and simulation of *Building Information Modeling.*[439] The infrastructure metaphor highlights the role of information transfer in design and construction practice, construing *design* as a raw material —a substance— to be collected, transported, and processed throughout the project's development. In the imaginary of practice this metaphor invokes, software in general, and *Digital Project* in particular, is the "pipeline" bound to replace artisanal channels for information circulation. While *Building Information*

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[439] The work on professional identities carried by the initiative for Technology and Self, led by Sherry Turkle at MIT, and —more specifically— the empirical study of simulation practices at ARUP, by Yanni Loukissas (see Loukissas, *Co-Designers.*), are important references for this study. My approach, however, differs in crucial conceptual and methodological aspects. For instance, I see limitations in their use of the concept of *simulation* to refer to computational representations, and the related metaphor, espoused in Loukissas's study, of simulations as a kind of *theatre.* While this metaphor suits their analytical framework —an inquiry into the constitution of professional boundaries between architects and engineers— for my purposes in this study casting computational design models as theatrical representations shuts down important domains of analysis. By construing computational descriptions as staged, or figural, descriptions of reality, the *simulation* frame invokes them as "mappings" to be thought through their resemblance to an actual, or projected, object-reality. My approach seeks instead to assign relevance to what goes on in both "sides" of the interface, recognizing the *technological agencies* of software as research *subjects* and *sites.*

Modeling is commonly represented as a neutral infrastructure enabling an effortless flow of design information —from abstraction into building— my analysis shows how the construction of this infrastructure is an arduous organizational, rhetorical and technological endeavor. The second metaphor is that of BIM as a *lingua franca* —a common language for all participants of design and construction. In the imaginary of practice this metaphor invokes, software in general, and *Digital Project* in particular, reduces the "social frictions"[440] arising from the multiplicity of languages of communication. In turn, design and construction practices outside the paradigm are construed as artisanal and unruly linguistic and cultural landscapes —the "Babel" figure is recurrent. This metaphor highlights a conception of natural languages and 2-D drawings —including those produced in software systems not certified as valid BIM platforms— as imprecise and incomplete forms of documentation. Paraphrasing Ivan Sutherland's pejorative description of pencil and paper drawings, those who seek the *lingua franca* of BIM construe non-BIM digital representations as "dirty marks on the screen." Or, as a kind of *dialect.* From this it follows that crucial to the realization of the *Building Information Modeling* project is the legal and cultural project of constituting BIM *certified* models as the authoritative form of design documentation[441].

Both metaphors frame the technological proposition of BIM within industrial, nineteenth century imaginaries of cultural and technological progress. On one hand, the idea of large infrastructures for the speedy transportation of information *goods* evokes images of canals, railroads, telephone lines and highways. On the other, the assumed linguistic superiority of BIM as a language, its supposed capacity to constitute a *lingua franca*, invokes colonial images of both culturalizing and deculturalizing anthropological endeavors. These metaphors speak of the imperial aspirations invoked by the technological project of *Building Information Modeling.*

Does software have politics?

The power of things

> In our accustomed way of thinking technologies are seen as neutral tools that can be used well or poorly, for good, evil, or something in between. But we usually do not stop to inquire whether a given device might have been designed and built in such a way that it produces a set of consequences logically and temporally prior to any of its professed uses.[442]

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[440] Phillip Bernstein, "Building Information Modeling," *At Issue: The Message in the Medium*, Winter 2011.
[441] See Appendix A for a discussion of the BIM standardization project.
[442] Winner, "Do artifacts have politics?," 3.

> Technology is basically neutral. It's kind of like a hammer. The hammer doesn't care whether you use it to build a house, or whether a torturer uses it to crush somebody's skull.[443]

In "Do Artifacts have Politics" Langdon Winner discusses ways in which technological artifacts can be understood as deployments of power structures[444]. As one example, he discusses Robert Moses's design for overpasses in the parks he laid out in New York[445]. Moses designed the overpasses to be extremely low making it impossible for buses to enter the parks. His bridges thus guaranteed that only "automobile-owning whites of 'upper' and 'comfortable middle classes[446]" accessed the parks. The overpasses preventing buses (which carried mostly low-income black passengers) from entering the park can be seen, therefore, as the enforcement of a politics of racial and socioeconomic prejudice. Long after Moses's death, Winner observes, the bridges he designed continue to prevent buses from entering the parks, effectively enacting a certain order of affairs of political significance. Like Moses's overpasses, understanding the technological systems with which our built environment is produced is a key form of democracy in an increasingly techno-scientific society.

Throughout this dissertation I have argued that, like Moses's bridges, software is an infrastructure — not a tool— for the design and production of our built environment. Can we then ask if there are any low overpasses in the infrastructure of *Building Information Modeling*? Even if software systems do not carry out, by themselves, an agenda of discipline and control, by establishing a space of alternatives and enforcing protocols of information exchange, software systems shape the conditions where practice takes place, and are, in themselves, sites of practice. To understand this relationship, however, it's crucial to discuss these system's ties with cultural, organizational and social structures in which they originate and operate — rather than assuming them as neutral, or transparent channels. This is why, throughout this study, I have referred to MIT's *Computer-Aided Design Project* and to the *Building Information Modeling* project as social, technical and cultural enterprises, with an intellectual and technological history worthy of discussion and debate.

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[443] "Noam Chomsky on the Purpose of Education," *Brain Pickings*, n.d., http://www.brainpickings.org/index.php/2012/03/13/noam-chomsky-on-the-purpose-of-education/.
[444] Winner, "Do artifacts have politics?".
[445] "Jones Beach," for instance.
[446] Winner, "Do artifacts have politics?," 21.

An expanded criticality

In "Image of the Self" Peter Galison asked about the Rorschach test "What logic of the self did the test embody?" and sought to "specify that notion of the self that fits the Rorschach measurement technology." In a similar voice, I have argued that in its interfaces, histories, data-structures, dozens of person-years of automation work, and its deployment through corporate vehicles, software systems for drafting, representation and analysis, embody ways of going about designing things. Paraphrasing Galison, I have tried to specify *what notion of design fits these technologies*?

One of the theses I submit is that there is a mutual construction of technology and design. It's not merely the case that conceptions of design are changing. What needs to be understood is that we build our conceptions of design out of the technological discourses and apparatuses with which, and within which, we design. An expanded criticality of the production of the built environment is thus needed to engage the social and technical specificity of the technological systems in which these practices are written.[447] I hope this dissertation contributes to fulfill that critical aspiration.

An ongoing inquiry

At the dawn of the information age Herbert Simon advanced a view of design as a "science of the artificial" that could be fully expressed by statements of declarative logic —and thus formalized as a scientific, measurable practice. While Simon's bold claim was a manifestation of larger techno-cultural changes, it powerfully synthesized and pre-figured the contemporary epistemology of design and architecture as techno-scientific, computational, "performance-based" and (for the most part) future-tense practices. Moreover, it helped design gain the kind of academic legitimacy that was elusive to trade schools, and its current placement in research universities as a field of rigorous inquiry and debate. However, it entailed a difficult paradox for researchers and educators. Conceived as a quantifiable and objective, design could be imagined as a process of optimization, and as theoretically independent from culture, material and craft. The formalisms of information theory and scientific management on which "Simon's shift" relied permitted, through their abstraction, a divorce —in Lewis Mumford's sense of the word[448]— from the material and cultural situatedness that is the object of architectural practice. Computational design and digital fabrication technologies, because of their cultural and technical roots in

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[447] Peter Galison, "Image of the Self," in *Things That Talk: Object Lessons from Art and Science* (New York: Zone Books, 2008), 277.

[448] For an interesting discussion about Mumford's concept of distance and dissociation, see Mindell, *Between Human and Machine.*

information theory and cybernetics —and because of the physical and cognitive distance they introduce between designers and artifacts— are doubly exposed to this paradox, and are too often explained as passive supports, or obedient makers, of design —as perfect slaves. However, software and hardware are not merely supports, or slaves, of our design *ideas*. Instead, they shape them (they are them!), and shape us back as designers and users.

The technologies we use to think about design today speak of other crafts, other materials, other cultures, than those historically associated with the professional worlds of design and architecture. I have called this condition broadly a "technological imagination of design," showing how it rests on specific social, historical and ideological supports. Instead of framing them under the rubric of novelty and progress, this dissertation has sought to demystify them, understand their histories and motives, and open them to critical scrutiny as techno-cultural artifacts. It has done so through archival historical research into the culture of technology production surrounding MIT's *Computer-Aided Design Project* in the postwar years, ethnographic studies of digital design and building practices —specially those at *Gehry Technologies*— and the construction, supported on critical perspectives on technology, of an interpretive framework of inquiry into design and computation.

8. APPENDIX

Appendix A: Standardization efforts in the AEC industry: a review

Outline

> Do standards for scientific instruments, frozen peas, tax forms, and automobiles have anything in common? Is that connection a fundamental one that says something about the way in which we organize our world, or is it merely a semantic curiosity, perhaps a leftover from previous and now archaic meanings?[449]

The goal of *Building Information Modeling* is optimizing information flows in the *Architecture, Engineering and Construction* (AEC) industry. Researchers contend that establishing digital format standards for design and construction "would enable the seamless flow of design, cost, project, production and maintenance information, thereby reducing redundancy and increasing efficiency throughout the lifecycle of the building[450]." Therefore, the success of the technological infrastructure for this information flow is contingent upon the establishment, adoption and enforcement of standardized protocols of information exchange. This section reviews the efforts of a diverse group of organizations and institutions to establish these protocols. To do so I rely heavily on studies of standardization in the AEC industry like those by Laakso, Howard and Bjork[451]. My review of these studies seeks to unpack a social dimension of *Building Information Modeling* advocacy, as an enterprise relying on persuasion, marketing, public perception within different fields, tensions between academics, professionals and institutions, as well as on concerns over technical functionality.

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[449] Busch, *Standards*, 2.

[450] Mikael Laakso, "The IFC Standard: a Review of History, Development and Standardization," 135.

[451] See, for example: Bo-Christer Björk and Mikael Laakso, "CAD Standardisation in the Construction Industry — A Process View," *Automation in Construction* 19, no. 4 (July 2010): 398–406., Howard and Björk, "Building Information Modelling – Experts' Views on Standardisation and Industry Deployment."

The size of the pie

A 200-page report by the *US National Institute of Standards* (*NIST*) premises the effort for the establishment of such protocols on a projection of the potential financial benefits to owners and operators.[452] The *NIST* estimates that the "cost of inadequate interoperability (…) among computer-aided design, engineering, and software systems."[453] to be close to USD 15.8 billion. The *NIST* attributes the majority of this cost to "to redundant data entry, redundant IT systems and IT staff, inefficient business processes, and delays indirectly resulting from those efficiencies."[454] According to the *NIST* report there are more than USD 10 billion in costs affecting owners and operators. The rest is divided between architects and engineers, fabricators, suppliers and contractors.[455]

Digital format standardization

The first attempts at creating an open standard for the digital representations of 2-D and 3-D geometry occurred during the late 1970s from a joint venture between Boeing, General Electric and Xerox, with the US Department of Defense[456]. The result of the effort was the *IGES* (Initial Graphics Exchange Specification) format, which was released in 1980 by the ANSI (American National Standards Institute) but was never widely adopted by the industry. Instead, *Autodesk*'s *DWG* (Drawing) format became the de facto standard format for digital drawings—mainly because of *AutoCAD*'s very large market footprint. In contrast with the *IGES*, which was an open format, the *DWG* was "closed"—its specifications were not available to the public. However, by the 1990s other market vendors had reverse-engineered the format and made it available to other software systems outside the *Autodesk* family —this is the origin of the *DXF* (Digital Exchange File) format.

CAD layer standardization

A "soft" form of standardization consisted on the establishment of conventions for color-coding the *layers* in CAD files[457], which developed in a "bottom-up" fashion in some countries but was formalized by

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[452] The NIST produced the report for the US Building and Fire Council.

[453] Gallaher et al., *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry.*

[454] As observed by Mikael Laakso, "The IFC Standard: a Review of History, Development and Standardization," 136.

[455] Gallaher et al., *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry.*

[456] Björk and Laakso, "CAD Standardisation in the Construction Industry — A Process View."

[457] Architects with knowledge of layer standards and data management were valuable for companies. In a sort of manual of technology for industry Kristine Fallon recommends companies examining new hires for their knowledge of layer color-coding conventions. Fallon, *The AEC Technology Survival Guide*, 78.

the ISO (International Organization for Standardization) in 1998[458]. A study by Howard and Bjork, however, suggests that the lack of resources and marketing to effectively promote this form of standards prevented it from being consistently and widely used among the population under study—Northern European architecture and engineering firms in 2007[459].

IFC standardization

Key to the standardization effort in the AEC industry is the idea that the information must be readable by different applications, constituting a common language, or *lingua franca*, for all design and construction participants[460]. Because of the scale of its potential impact across professions Laakso describes *IFC* standardization as "one of the most ambitious IT standardization efforts in any industry."[461]

The crucial effort towards standardization in the design and construction industries is the *IFC* (Industry Foundation Classes) format, premised on the idea of constituting an "open" standard without ties to particular companies or software vendors. The idea, promoted by an industry consortium and supported by members of academia, is to provide an open, platform-independent, "stable" data representation for design intent to be "carried" or "retained" throughout the design and construction process. The *IFC*s are object-oriented representations of architectural elements providing "object" classes for describing architectural elements such as beams, walls, and doors. These "objects" are defined in a way that relevant information can be associated to particular instances of an object as attributes. For instance, a door instance could have attributes specifying its model, fabricator, price, and other supply-chain information. While a number of committed academics advocate its use in the name of openness and independency from software vendors, the adoption of the format has been slow. It's likely that the *IFC* standard continues to be sustained by an academic interest on open standards, and by government regulations that decree its implementation in industry, but it's probable that the larger market footprint of proprietary formats of commercial software systems such as *Autodesk*'s Revit will become the de facto standard of work and information exchange within the AEC industry.[462]

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[458] ISO-International Organization for Standardization, "ISO 13567-2:1998," Text, *International Organization for Standardization*, March 1998, http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=26766.

[459] Rob Howard and Bo-christer Björk, "Use of Standards for CAD Layers in Building," *Automation in Construction* 16, no. 3 (2007): 290–297.

[460] A good definition of the intent is Gallaher's report: "Computer applications use *IFC*s to assemble a computer-readable model that constitutes an object-oriented database. This database may be shared among project participants and continue to grow as a project goes through design and construction and enters operation." Gallaher et al., *Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry*.

[461] Mikael Laakso, "The IFC Standard: a Review of History, Development and Standardization."

[462] In the appendix I discuss the *IFC* standardization effort in more detail.

Institutional advocacy: IAI and BIMSmart

A precedent of the *IFC* effort can be traced to the 1985 ISO *STEP* (Standards for the Exchange of Product Data) project, which laid the foundations for the 1996 IAI (International Alliance for Interoperability). The IAI gathered the efforts towards standardization started in 1994 by an Autodesk led group of 12 American companies using *AutoCAD*. The International Alliance for Interoperability (IAI, later called BuildingSMART) is the body in charge of promoting and implementing *IFC* standardization in the US (and later taken up by companies in Europe) since the 1990s. This organization released the first version of the *IFC* format in 1997 with the goal of making a platform independent "Open BIM" standard for international use.[463]

Slow adoption

The *IFC* format remains a contested standard. Howard and Bjork suggest that "there needs to be a reality check on the IAI [members] who claim that *IFC*s are used across the world when they are mainly used by academics."[464] Advocates of BIM demand more effective marketing efforts to highlight the benefits of the paradigm among governments and owners, and its adoption by top firms, in order to stimulate its wide adoption. Howard and Bjork argue for proper training in universities, and ask institutions to recognize "the need for a new specialism in applying technology, standards and modelling, and being responsible for spatial coordination … How should a BIM specialist and training be built into the construction process?"[465] For some researchers the *IFC* "is at high risk to fall into the trap of 'design by committee' if goal orientation does not remain a high priority".[466] Experts see the commitment of major stakeholders to the BIM enterprise as key to its success.

> IFCs are not yet used and most industry is unaware of them. Development has been top down. The people who produce drawings do not care about IFCs but if

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[463] The IAI conceived the *IFC* as "a common data schema that makes it possible to hold and exchange data between different proprietary software applications. The data schema comprises information covering the many disciplines that contribute to a building throughout its lifecycle: from conception, through design, construction and operation to refurbishment or demolition." Howard and Björk, "Building Information Modelling – Experts' Views on Standardisation and Industry Deployment."

[464] The authors remark that "…Standards are nominally supported; no one is against them but few apply them comprehensively. National groups have often been successful in implementing modest standards such as those for CAD layers, but international implementations need to be tailored for local cultures and conditions. Official endorsement, preferably by ISO, can give wide recognition but is no substitute for promotion and software implementation." Ibid., 18.

[465] Ibid., 14.

[466] (Purao et al 2008) cited in Mikael Laakso, "The IFC Standard: a Review of History, Development and Standardization," 171.

> there are products to help them they would make use of them. Why should construction industry firms commit to something irrelevant to their practice?

As researchers have shown the adoption of BIM standards has been incomplete. While there are important advances in countries like Finland and Singapore, it's usually very difficult to have all the actors in a construction process abide by the same protocols of information exchange.[467] Different professionals have different opinions as to what should be standardized, and believe that the de facto standards—those that result of widespread adoption, such as AutoDesk's *DWG*—should be formalized by ISO.[468] Most commercial software applications are *IFC* compatible and are able to export and import *IFC* files.[469] However, evidence collected during fieldwork showed the *IFC* to be a requisite format for sharing, but not operational. Typically *IFC* models would be referred to as "dead" geometry.[470]

Government support

A report by Prince Charles Kwabi shows how in the US, the National Institute of Building Science created a charter and set in motion a National BIM Standard *Project* Committee in 2005 to deal with standards and trends of the BIM framework in the country with the flexibility of incorporating developments from ISO (NIBS, 2012). Similarly, in the UK, the Government Chief Construction Advisor suggested a roadmap and strategy for progressive use of BIM in government projects plus the need to rise to the BIM challenge through training and support. As a result, the UK Cabinet Office disseminated in May, 2011 the "Government Construction Strategy" that indicated the collaborative use of BIM on its building programs by 2016 (BIS, 2011).[471] Supporters of the *IFC* standard expect that government intervention will raise the awareness about the open standards. An example, perhaps, of the Negroponte paradox discussed in Chapter 3: the open and participatory aspects of technologies for design frequently seem to require, in the practical world, of top-down measures.

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[467] Howard and Björk, "Building Information Modelling – Experts' Views on Standardisation and Industry Deployment"; ibid., 12.
[468] Howard and Björk, "Building Information Modelling – Experts' Views on Standardisation and Industry Deployment."
[469] BuildingSMART maintains a database of *IFC* compliant software systems, which by November 2011 registered 148 entries, 17 of which were software systems intended for architects. Kjetil Espedokken and BuildingSMART, "*IFC* Supporting Applications," *buildingSMART: International Home of OpenBIM*, November 10, 2011, http://buildingsmart-tech.org/implementation/implementations.
[470] More on "dead geometry" on Chapter 5.
[471] Prince Charles Kojo Kwabi, *Does the Management of* BIM *Implementation of a Project's Design Phase Require a Specialist?* (Manchester, UK: University of Salford, School of Built Environment, March 9, 2012).

Appendix B: Software

Autocad

Never underestimate the power of a widely distributed tool.[472]

John Walker credits his company, *Autodesk*, with having made available the first CAD system that didn't need a mainframe computer, thus reducing the cost of CAD by several orders of magnitude.[473] The company was founded by 16 partners in the Bay Area, with the technical leadership of Walker and Dan Drake, who previously were principals at *Marinchip Systems*. The company incorporated as a California corporation in April 9, 1982, driven by Walker's sharp business vision:

> I can think of no business (well, legal business) where we can start-up with so little capital or downside risk. If this business looks shaky to you, where do you expect to find a better deal? I cannot imagine any scenario other than total collapse of society in which the sales of microcomputer application software will not grow by a factor of 10 in the next five years. The big vendors of small machines have not only not entered the software business, they appear totally in awe of it and willing to grab any product and promote it to sell their machines.[474]

Originally, its founders imagined *Autodesk*, the company, as the provider of an "office automation system for small computers ... a computer model of an office environment. ... [providing] file cards, file boxes, a calendar, etc. ... connected to a very simple database and query system. The entire system is intended to be extremely user friendly and straightforward."[475] However, the success of the first version of *AutoCAD* led the company to focus its efforts on CAD. *AutoCAD* originated from a program called *Interact* written by Mike Riddle —one of the company's founders.[476] According to Walker, a key strategic decision by the board was to develop *AutoCAD* as a system that could be extended by third party vendors, therefore

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[472] Walker, J. (1994, 3 1). *The Autodesk File.* Retrieved 05 26, 2009, from Fourmilab: http://www.fourmilab.ch/autofile/ p. 300.

[473] See Walker, J. (1994, 3 1). *The Autodesk File.* Retrieved 05 26, 2009, from Fourmilab: http://www.fourmilab.ch/autofile/

[474] Walker, *The Autodesk File*, 23.

[475] Ibid., 76.

[476] In an interview, Mike Riddle recalls how (before *Autodesk* existed) Riddle demoed *Interact* for John Walker. Walker stayed quiet for the 45 minutes the demo lasted. Once finished, Riddle recalls, Walker simply asked: "Do you know what you have here?" "No" Riddle replied. "A fortune" said Walker. "OK, Show me how!" was Riddle's response. *Interact* was then rewritten and called *MicroCAD*, the first version of *AutoCAD* —which became was *Autodesk*'s "hit" product. Instead of a lump sum Riddle negotiated 10% of royalties for the product and all derived products (enough to make him a millionaire). See Mike Riddle, "Mike Riddle on Interact, Auto*CAD* and the early CAD industry," mp3, date unknown, http://www.digibarn.com/stories/mike-riddle/MP3_96_mike-riddle1.mp3.

fostering a network of products that created stronger dependency between their product and its clients[477]. By the mid nineties 85% of architecture offices owned *AutoCAD* licenses[478]. During the early 80s *Autodesk*'s business strategy to outmaneuver competitors consisted in aggressively releasing new features. These features were mostly digital versions of drafting routines. In a 1983 memo John Walker discusses new features to be introduced.

> With the features scheduled for the 1.40 release, plus the items which we hope to have in 1.5 (notably dashed lines, double walls, and some form of attribute collection and dissemination), we will have accomplished most of the goals inherent in a 2D drafting system.[479]

3-D modeling was not part of the initial releases, and was only introduced following marketing—not productivity—concerns. Walker interpreted *AutoCAD*'s client base, and pushed 3-D capabilities even though there was no explicit demand for it. However, it provided an attractive feature that would lure customers and give *Autodesk* a competitive advantage in the software market.[480]

The capacity to draw 3D objects was thus *added to AutoCAD* on top of its drafting capabilities mainly as a marketing move, as a feature. In order to implement the new 3-D modeling capabilities without having to re-write large portions of the software's code and thus slowing its the development pace, Walker proposed a "low-rent 3-D" notion, which required a minimum of intervention on *AutoCAD*'s drafting oriented data-structures[481].

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[477] The developers of Rhinoceros, McNeel and Associates, follow the same business principle today. This strategy is explained by Ferguson and Morris: "As the infrastructure of Autodesk-compatible software products steadily increases, so do [sic] the customer switching costs. And as the product becomes more pervasive and customers routinely exchange Autodesk files, the lock-in can become very strong" Charles H. Ferguson and Charles R. Morris, *Computer Wars: How the West Can Win in a Post-IBM World* (Times Books, 1993). Cited in Fallon, *The AEC Technology Survival Guide*, 167.

[478] Fallon, *The AEC Technology Survival Guide.*

[479] Walker, *The Autodesk File*, 96.

[480] Walker explains the business rationale of 3-D modeling: "First, there is a natural tendency to evaluate a package from the features it has, and a package limited to 2D cannot look as good on a cursory examination as a 3D package. Second, many companies will reason, 'look, all we need is 2D today, but who knows about tomorrow; we better buy a package that has 3D just in case rather than get stuck with a dinosaur.' ... The impact of rotating an object in 3 space at Comdex is many times that of zooming in on a flat drawing." Ibid., 97.

[481] The strategy to implement 3-D in *AutoCAD* consisted of adding a 3-D plane location to each layer in the drawing, where the objects drawn on that layer would reside. The viewing plane would be specified following the same logic, adding parameters for the kind of strategy used to project the vectors unto the screen (isometric, perspective, clip depth, etc.) and was the origin of the idea of the viewport. Specifying the third dimension in such modular way helped the developers of *AutoCAD* to implement 3-D in a way that was not disruptive of the more established portions of the code and data structures. This particular implementation of 3-D was based on shifting drafting planes in space. An added feature was the *extrude* option, which allowed users to specify a depth to each layer. Every time the elements in the layer were regenerated, a new set of points, or vectors, would be generated by the system for each point, connecting the original vector to another one in a parallel plane located at the specified depth distance from the original drawing plane. At the moment Walker saw these features as minor additions to *AutoCAD* relative to "major" ones such as cross-hatching, line types, fillets, etc. He also saw their great potential as revenue generators:

"Electric Malcolm"

In 1983 a young intern was appointed for a summer job at the *Autodesk* headquarters in Sausalito, California. Malcolm McCullough, a UCLA architecture student with a knack for manual drafting, spent the better part of that summer testing and generating sample drawings for *AutoCAD* release v.1.4. After that summer some of his drawings were frequently featured in *Autodesk* brochures.[482] By that time *Autodesk* was already a medium-sized organization with around a hundred employees working inside the headquarters, developers working offsite from different parts of the world and third-party developers extending the functionalities of the core system.[483] At its inception, however, *AutoCAD* was not conceived or developed under heavy supervision or influence of architects and designers. *Autodesk* co-founder and CEO John Walker admits that McCullough was one of the first "real" draftspersons giving feedback and recommendations to the developing team.

"Malcolm was the first person really talented in drawing to work for *Autodesk*, and his work with *AutoCAD* helped both by generating good sample drawings and by identifying the most important features needed in real professional drafting.[484]"

Engineers at *Autodesk* were so impressed by McCullough's "creative" drafting that they developed a tool to record his drafting process with the purpose of replaying it later internally, and in showrooms. They dubbed it "Electric Malcolm". The tool was never implemented in the commercial versions of *AutoCAD* due to "stability problems."

Members of a professional culture distant from architectural, spatial and visual concerns defined the data-structures used to store geometric data. As shown by the "Electric Malcolm" anecdote (see Frame), the *AutoCAD* developing team didn't have much idea about drafting —or architecture— but it doubtlessly transformed its practice.[485]

"Just think of the difference in our COMDEX literature of 'Now with 3D' vs. 'Now with crosshatching and dashed lines.'" Ibid., 183.

[482] Walker, J. (. (1994, 3 1). *The Autodesk File.* Retrieved 05 26, 2009, from Fourmilab: http://www.fourmilab.ch/autofile/

[483] As an example Bob McNeel's now widely used *Rhinoceros* started as surface modeling plug-in for *AutoCAD.*

[484] Walker, *The Autodesk File*, 185.

[485] In an informal conversation between Phil Bernstein, vice-president of Autodesk, and the author, Bernstein said jokingly that, back in the 1980s, he could drive around a city and identify with which version of *AutoCAD* each building had been designed.

Digital Project

Origins and relationship to Frank Gehry

Digital Project is an "offspring" of the software *CATIA* (Computer Aided Three-dimensional Interactive Application), developed by the French aerospace company *Dassault Systemes*.[486] *Dassault* developed *CATIA* from *CADAM* (Computer-Aided Drafting and Manufacturing), a program developed by the aircraft and weapons manufacturer Lockheed and purchased by *Dassault* in 1975.[487] *CATIA* was first used for architectural modeling purposes by members of Frank Gehry's office, who adopted it because at the time it was the only software in the market capable of representing curved surfaces as smooth surfaces (at the time software systems like 3DMax represented curved surfaces as planar triangles, making the unusable for fabrication processes).[488] Discussing the adoption of *CATIA* by Gehry, Dennis Shelden, Chief Technology Officer of *Gehry Technologies*, recalled that the *CATIA*'s parametric modeling capacities were not the reason for its adoption by the office.

> There was this parametric thing, which, I think, we thought was interesting more than what we thought it was relevant, so (...) we, rather than saying "oh we've always been waiting for this", it was kind of a you know "this is something very promising, let's see if we can use it.[489]

CATIA also offered material mapping capabilities, curvature analysis, and other features that were appealing to Frank Gehry's team.[490] To develop the system Gehry established a partnership with *Dassault Systemes* that allowed the firm to adapt and further develop a special version *CATIA* tailored for the purposes of the firm. The partnership involved a team of 14 French engineers from *Dassault* sent to the US to work on a first version and establish the alliance. Gehry's in-house technology and IT department developed into a global consultancy firm, *Gehry Technologies*, that offers services to many firms including,

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[486] Interestingly, the origins of another very influential software system for design are also related to the aeronautic industry. *Rhinoceros*, the widely used surface modeler for windows, started with a team of Boeing mathematicians who were hired by Robert McNeel & Associates in the early 80s (from an informal conversation with Bob McNeel).

[487] M Bozdoc, "CAD Chronology: The 70's," Resources and Information for Professional Designers, CAD *Cronology*, 2003, http://mbinfo.mbdesign.net/*CAD*1970.htm.

[488] This issue will be further discussed. Shelden, "Interview with Dennis Shelden."

[489] Ibid.

[490] Shelden on the adoption of CATIA: "CATIA was chosen before I got there for a bunch of reasons, one is the only curve, curve, smooth-curve ahm, CAD program out there, lots of things like 3D studio existed, but represented curved things as triangles, right? So from a production process it was unusable, I mean you couldn't cut the things so this idea of the software having an impact, just the hum, the hum, the encoding of geometry that the particular software package was having an impact on process that you may or may not want, or that you don't want, was a big deal, so, most of the tools that are out there were unusable because, you know, just to put it simply you couldn't build one of those shapes, cut it and get a curve back, and get a curve back, right? You get a polyline back, right? And so the information, the geometry, instantly degraded." Ibid.

but not limited to, Gehry's.[491] Today (2012) *Gehry Technologies* employs around 120 people —around 3 times more people than *Gehry Partners.*

Digital Project figures prominently in the landscape of software systems for architecture, in part as a result of the great exposure it derives from the allure of Gehry's own architectural celebrity. A common misconception is that Gehry's buildings originate inside *Digital Project*'s environment. Instead, Gehry's structures are modeled on paper and cardboard models before they are modeled in *Digital Project.* Only when the design is convened the physical model is 3-D scanned and shared with *Gehry Technologies.*

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[491] Up until 2011 these services were centered on developing new versions of Digital *Project*, training organizations in its use, and providing parametric and Building Information Modeling services to firms. In 2011 GT stopped developing new versions of Digital *Project* to focus on the development of web based services. Dassault assumed the service for existing DP clients. See [REF] With *Autodesk* investment in the company GT is expected to start providing a wider specter of services and software consultancy.

Appendix C: Brief notes on design and cybernetics

Introduction

"The voices that speak the cyborgs do not speak as one" (Hayles 1999, 112)

Considering the claims of universality made by members of disciplines like economy and sociology about the logical and epistemological framework of cybernetics, that is, of the applicability of such framework beyond the boundaries of the sciences of communication and control (which by that time already included the biological sciences and psychology) Norbert Wiener, skeptical, wrote that "from believing this is necessary, they come to believe it's possible."[492]

Despite Wiener's skepticism, most disciplines —including planning and design— were not immune to the massive realignment of discourse and practice around the idioms of communication and control that characterized post-war society.[493]

Through a few examples, this essay illustrates ways in which information theoretical idioms informed conceptions of design and creativity throughout the twentieth century.

Design

During the second post-war era ideas from systems theory and cybernetics led designers and design researchers to see the design process as a flow of information. Instrumental to this reconfiguration was Shannon and Weaver's model of communication that provided an idiom for describing communication in terms of sources, signals and messages.[494] This idiom, intended primarily for improving telephonic communications, became a source of inspiration and a suitable a metaphor for thinking about design and

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[492] Wiener, N. (1961). *Cybernetics: or Control and Communication in the Animal and the Machine.* Cambridge: MIT Press. P. 162.

[493] Bowker accounts for the appropriation of the cybernetic idiom by other fields of scientific practice with the notion of "triangulation" in virtue of which a scientist from a field uses the rhetoric of another to gain legitimacy. Bowker theorizes that the generality of cybernetics (what could be more general than a "science of messages"?) offers a fertile ground for these metaphorical triangulations: "An isolated scientific worker making an outlandish claim could gain rhetorical legitimacy by pointing to support from another field – which in turn referenced the first worker's field to support its claims. The language of cybernetics provided a site where this exchange could occur." See Bowker, G. (1993). How to be Universal: Some Cybernetic Strategies. *Social Studies of Science*, *23* (1), 107-127. p. 116. For critical discussions of cybernetics and society see Hayles, Pfaffenberger, Galison

[494] See Shannon, C., & Weaver, W. (1962). *The mathematical theory of communication.* Urbana: University of Illinois Press.

creativity.[495] Let's take as an example of this rhetoric strategy a 1963 quote from the first page of American architect Peter Eisenman's doctoral thesis:

> "The essence of any creative act is the communication of an original idea from its author, through a means of expression, to a receiver. The means of expression must be such as to transmit the original intention as clearly and fully as possible to the receiving mind[496]."

These words commit to a view of creative design as the transmission of information, and conceive the design process as the transmission of this information. The logical implication of this rhetorical contraption is that of design media as clean, neutral, channels, and of their use as a process of translation, or externalization.

Alise Upitis writes that cybernetics and Information Theory reconfigured post-war society's conceptions of nature and design, and focuses on how architectural pedagogy, under the influence of the collective of architects and designers know as the *Design Methods* movement, embraced a conception of creativity as the ability of a person to provide a number of diverse –yet "acceptable"- solutions to a given design problem.

> The degree of novelty of which the person is capable, or which he habitually exhibits, is pertinent to our study. This can be tested in terms of the frequency of uncommon, yet acceptable, responses to items.[497]

The notion of creativity, Upitis observes, is thus related to the capacity of deviating from the convention, a motif that is present in many discourses of design. The creative person is conceptualized as an input/output device (a black box), whose outputs can be measured scientifically. The Design Methods movement conceptualization of creativity objectifies it: if creativity is a measurable variable susceptible of assessment it can be successfully incorporated in the market economy.

In 1933, Harvard Professor George Birkhoff boldly declared a mathematical theory of aesthetics by declaring the "aesthetic measure" as $A = O/C$ (Aesthetic measure equals order divided by complexity) and

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[495] An example of the use of this rhetoric is this 1963 quote from Peter Eisenman: "The essence of any creative act is the communication of an original idea from its author, through a means of expression, to a receiver. The means of expression must be such as to transmit the original intention as clearly and fully as possible to the receiving mind." Eisenman, P. (2006). *The Formal Basis of Modern Architecture.* Cambridge: Lars Muller Publishers.

[496] Peter Eisenman, *The Formal Basis of Modern Architecture: Dissertation 1963, Facsimile*, 1st ed. (Lars Müller Publishers, 2006).

[497] Guilford cited in Upitis, A. (2007). *Architectural Pedagogy and Psychological Testing in Great Britain, 1958-1968.* Massachusetts Institute of Technology, Architecture. Cambridge: Unpublished. A Marxist reading of Guilford's conceptualization of creativity may point out how it is suggestive of a superstructure (insinuating, perhaps, the presence of a manager?). Design as a production activity *separate* from judgment entails a certain sense of disempowerment. In this sense the conception of creativity enforced in these accounts is revealing of an ideology of production and corporate capitalism. It is also suggestive of the –
relatively late- arrival of scientific management ideas into design discourse.

by testing it on a number of designs.[498] Stiny and Gips cite Birkhoff's work on aesthetic measure as a source of inspiration for their "Algorithmic Aesthetics", where the authors contended that "Just the attempt to represent aesthetic ideas or specific approaches to understanding and evaluating works of art in terms of algorithms is salutary."[499] The conceptual framework of information theory resonates in Stiny and March's later formulation of "design machines" –theoretical devices for producing designs phrased in the idiom of Shannon and Weaver.[500]

Early enthusiasts of computer art make a different reading of the cybernetic idiom. Early computer artist Frieder Nake writes that the adoption of information theory in the early moments of computer art meant that "A painting could be clearly considered the carrier of signs (…) On each level of such a hierarchy the statistical information content –according to Shannon's axiomatic definition- could be determined."[501] Under the intellectual influence of Max Bense's *Projekte Generativer Asthetik* ('*Project* of Generative Aesthetics'), that –just like the Design Methods movement- defined creativity as the capacity of an agent to produce "deviations from the norm."[502]

Cybernetic serendipity

The 1968 London exhibition "Cybernetic Serendipity" gathered a collection of projects focused on exploring the application of communication and control sciences to the artistic practices. The projects included drawing machines and software, computer-generated music, poetry, language and kinetic sculptures. The exhibition included works by Stockhausen, Jean Tinguely, Frieder Nake and Georg Nees. The only architectural installment in the exhibition was John Week's conveniently titled "Indeterminate dimensions in architecture", a relatively shy enunciation of the potential of computers to calculate structural stresses under varying conditions or randomize façade designs. Week's proposal nevertheless captured the spirit of the cybernetic promise of architectural homeostasis:[503] "The impact of the standard analysis on the varying conditions has resulted in buildings which are everywhere different, since the

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[498] Birkhoff, G. (2003). *Aesthetic Measure.* Kessinger Publishing. Stiny, G., & March, L. (1981).

[499] Stiny, G., & Gips, J. (1978). *Algorithmic Aesthetics: Computer MOdels for Criticism and Design in Arts.* Berkeley and Los Angeles: University of California Press. p. 6.

[500] Design Machines. *Environment and Planning B* , 245-255.

[501] Nake, F. (2005). Computer Art: A Personal Recollection. *Proceedings of the 5th conference on Creativity & Cognition* (pp. 54-62). New York: ACM. In this paper Nake makes the intriguing proposition that digital media are explorations of algorithmic signs.

[502] Bense, M. (n.d.). *projekte generativer ästhetik.* (C. Klutsch, Producer) Retrieved from Computer Kunst: http://www.computerkunst.org/Bense_Manifest.pdf

[503] Homeostasis is a concept derived from the biological sciences that postulates the equilibrium of an organism and its environment. Cyberneticians' use of the term is based on their equivalent conception of organism and machine. Week's move can be seen as a cybernetic derivation of Le Corbusier's famous contention that the house is a *Machine a vivre.*

design parameters differ."[504] These machines' —if I may— *sensibility* recall British cybernetician's Ros Ashby's *Homeostat*, a machine whose sole purpose was maintaining its state in an unstable and contingent environment via negative feedback. Andrew Pickering suggests that the *Homeostat* proves that

> (...) Cybernetics grabs on to the world differently from the classical sciences. While the latter seek to pin the world down in timeless representations, cybernetics directly thematizes the unpredictable liveliness of the world, and processes of open-ended becoming.[505]

This process of becoming embodies the cybernetic aspiration of performance, understood as a dynamic equilibrium between the organism and its environment.[506] However, in his doctoral dissertation, Christopher Alexander used the *Homeostat* as a metaphor for the design *processes* itself.[507] Alexander contended that design could be understood as an opposition between form and environment and design processes as an opposition between the –mental- image of a design context and the –represented- image of a projected form.[508]

The performative aspiration of cybernetics, embodied in the *homeostatic* behavior of a machine in non-linear dialogue with its environment, unfolds in different discursive and material clothes in contemporary design practice. Net art, abstract photography, and the loosely tied collection of art and design practices under the label of "generative" offspring in one way or another from the artistic practices above-mentioned, technical explorations phrased in the language of information theory and influenced by what Eco called "our culture's fascination with indeterminacy". The constrained indeterminacy that machine agency conveniently affords seems to suit our taste very well.[509]

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[504] Reichart, J. (1968). *Cybernetic Serendipity.* London: Studio International. p. 69.

[505] Pickering, A. (2009). Cybernetics and the Mangle. *Social Studies of Science* , 413-437. p. 430.

[506] In "The Ontology of the Enemy" Peter Galison calls systems research, game theory and cybernetics as the "Manichean sciences" because of their fundamental reliance on struggle and opposition between forces. Galison, P. (1994). The Ontology of the Enemy. *Critical Inquiry* , 228-266.

[507] Alexander, C. (1964). *Notes on the Synthesis of Form.* Cambridge: Harvard University Press.

[508] Eco's formulation of the cultural significance of the open work for "contemporary poetics" is heavily influenced by information theory. In Eco's notion of the "open work" the "information value" or "meaning" of a piece is multiplied by virtue of its non-determined form: Eco describes this operation cybernetically as the "growth and multiplication of the possible meanings of a given message", or as an "increase in information". Eco, U. (1989). *The Open Work.* (A. Cancogni, Trans.) Cambridge: Harvard University Press. p.43. Deviation from the norm is a means to increase the work's "information levels" and therefore to achieve a greater aesthetic value. Eco uses Information Theory for formulating a theory of the probabilistic nature of the aesthetic experience. A new conceptualization of the composer ensued: "The distance between a plurality of formal worlds and undifferentiated chaos, totally devoid of all possibility of aesthetic pleasure, is minimal: only a dialectics of oscillation can save the composer of an open work." Ibid. p.65.

[509] What vision of the world does it imply? Eco proposed these "open" works of art as epistemological metaphors, formulations of a view of the world marked by the advancement of techno-scientific knowledge. "The repercussion, within formative activity, of certain ideas acquired from contemporary scientific methodologies-the confirmation, in art, of the categories of indeterminacy and statistical distribution that guide the interpretation of natural facts." Eco, U. (1989). *The Open Work.* (A. Cancogni, Trans.) Cambridge: Harvard University Press. p. 87

Embodiments of the cybernetic metaphor in contemporary architectural design discourses are manifest in narratives of computationally enhanced design that characterize both designs and design descriptions through labels such as "variation", "responsiveness" and "performance",[510] showing that the cybernetic idiom is as present as ever.[511]

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[510] The meaning of these terms in contemporary design discourse is context-specific, multiple, unstable, at times exchangeable, and generally vague. Performance, for instance, can refer to the structural and material stability of an architectural object, or to its energy expenditure, or to the moral value of a design process guided exclusively by "objective" criteria. I transcribe a couple of examples of contemporary cybernetic rhetoric in architecture: "New, more adaptive processes for generating form increasingly demand that we regard these forms as organisms in the literal sense, capable of finding methods for optimizing themselves to fit their host environments." Verb. 50. And Kas Oosterhuis description of his design methodology: "This architecture is not static or unchanging, but more like a complex organism, which unfolds and evolves over time. Real-time input and exchange affects the shape, use, and appearance of their buildings and installations. The possibilities of these instantaneous processes can only be carried out after deep research and experimentation." (p. 182)

[511] Open Work offers very insightful thoughts on the migration of terms from science to the arts. About the use of terminology like "indeterminacy" and "statistical distribution" in aesthetic discourse Eco points out how it has often received negative response from "purists" (p.88). He also writes that terms used in aesthetic and philosophical discourse, like "form" and "germ", were also "imported" from scientific discourse. Eco takes that to indicate a constant –and healthy- flux of knowledge that science makes available to culture (except that science *is* culture). At any rate Eco's account of the scientific aspiration of artistic practices in the second half of the twentieth century seems to be relevant to contemporary design cultures, always so eager to incorporate scientific discourses (see previous note) into the "rhetorical spaces" their practice relies on.

Appendix C: JAVA/Processing code for Interactive Data Visualization

```
// Dissertation chapter 7 data viz sketch
// a visualization depicting the information flow in a BIM coordination process.

import java.lang.IllegalArgumentException;

import controlP5.*;
ControlP5 cp5;
int knobValue = 100;
Knob myKnobA;
Knob myKnobB;
Range range;
Slider date_slider;
float[] datesarray;

PFont pfont = createFont("verdana",20, false); // use true/false for smooth/no-smooth
ControlFont font = new ControlFont(pfont,200);

void setup()
{

  // initialize picking buffer
  pick_buffer = createGraphics(width, height, P2D);

  // initialize data structures

  issue_set = new ArrayList();
  iset = new ArrayList();
  dates = new ArrayList();
  organizations = new ArrayList();
  buildings = new ArrayList();

  date_counter = 0; // keeps track of the active date, relates to the ArrayList "dates"
  iset.clear();

  // initialize stage

  size(MY_WIDTH, MY_HEIGHT);
  stroke(255, 255, 255);
  smooth();
  noStroke();
  background (0);
```

```
  myFont = createFont("verdana", 10);
  textFont(myFont);

  // initialize picking buffer
  pick_buffer = createGraphics(width, height, P2D);
  pick_buffer.beginDraw();
  pick_buffer.noFill();
  pick_buffer.strokeWeight(2);
  pick_buffer.endDraw();

  // parse issues
  String lines[] = loadStrings(DATASOURCE);

  for (int i=0; i < lines.length; i++)
  {

    // creates an array with the comma separated elements of each line
    String values[] = split(lines[i], ",");
    try {
      Issue issue = new Issue(values);
      issue_set.add(issue);
      good_issues_count += 1;

    } catch (Exception e) {
      bad_issues_count += 1;
    }
  }
  parse_dates();
  datesarray = new float[dates.size()];
  parse_buildings();
  make_gui();
}

void draw() {
  background(0);

  pick_buffer.beginDraw();
  pick_buffer.background(0);
  pick_buffer.endDraw();
  selected_issue = -1;

  draw_rings();
  update_info();

  if (iset.size() > 1){
    update_date();
  }
```

```
  }


  //void mousePressed() {
  //  test_load_random_image();
  //}




  // SOURCE

  String DATASOURCE = "clean_03.csv";
  String IMAGEFOLDERPATH = "/Users/Daniel/Dropbox/0 BUILDERS_DATAVIZ/1
CODE/bimviz/data/issue_images";

  // DATA STRUCTURES

  ArrayList issue_set;              // this arraylist is contains all of the data
  ArrayList iset;                   // this arraylist contains only the "active" data (changes
with date)
  ArrayList dates;                  // this arrayList is to store the dates
  ArrayList organizations;             // this arrayList is to store the organizations
  ArrayList buildings;                 // this arrayList is to store the buildings

  PGraphics pick_buffer;
  int selected_issue = -1;

  int bad_issues_count  = 0;
  int good_issues_count = 0;
  int date_counter;
  int viz_mode = 0;

  Date active_date;

  // DATA FIELDS

  String FIELDS[] = {"INDEX", "BUILDING", "LEVEL", "TRADE", "INT CODE", "DISCIPLINE", "DWG REF",
"ZONE", "GRID X1", "GRID X2", "GRID Y1", "GRID Y2", "GT CODE", "KEY", "ISSUE DESCRIPTION",
"OPENING DATE", "STATUS", "ACTION BY DATE", "LAST CHANGE", "ACTION", "BY NAME", "ORGANIZATION",
"RFI", "EXT MEETING DATE", "EXT. MEETING ACTION"};
  String ORGANIZATIONS[] = {"AEDAS", "AREP", "SSJV", "DDD", "ETA", "EVS"};
  String BUILDINGS[] = {"GAL", "ICU","PG", "PT", "SWI"};
  String IMAGES[] = listFileNames("/Users/Daniel/Dropbox/0 BUILDERS_DATAVIZ/1
CODE/bimviz/data/issue_images");

  // VISUAL VARIABLES
```

```
  CheckBox cb; // checkbox

  int RAD = 800;
  int SEPARATION = 250;

  int RAD_INNER = 300;
  int RAD_MID = 550;

  int INFO_PANEL_X = 1000; //10;
  int INFO_PANEL_Y = 600; //15;

  int ISSUE_PANEL_X = 1000;
  int ISSUE_PANEL_Y = 150;

  int MY_WIDTH = 1300;
  int MY_HEIGHT = 1000;

  int CENTERX = 500;
  int CENTERY = 500;

  int SLIDER_WIDTH = 700;
  int SLIDER_POSX = 50;
  int SLIDER_POSY = 100;

  int KNOBS_X = SLIDER_POSX + SLIDER_WIDTH + 50;
  int KNOBS_Y = SLIDER_POSY;
  int KNOB_SEPARATION = 60;
  int KNOB_RADIUS = 20;

  int petal_switch = 0;
  int tree_switch = 0;

  // COLORS

  color[] colors_organizations = {color(0, 0, 255), color(91, 198, 140), color(90, 255, 126),
color(188, 255, 97), color(191, 214, 0), color(204, 153, 0)};
  color[] colors_buildings = {color(167, 171, 240), color(59, 151, 255), color(100, 100, 255),
color(101, 97, 170), color(163, 148, 255)};

  // FONTS

  PFont myFont; // used to create font


  void parse_dates(){
    // populates a global ArrayList with the dates
```

```
  int i;
  Issue issue;
  for (i = 0; i < issue_set.size(); i++){
    issue = (Issue)issue_set.get(i);
    if (dates.contains(issue.open_date)){
    }
    else{
     dates.add(issue.open_date);
    }
 }
}

void parse_organizations(){
  int i;
  Issue issue;
  for (i = 0; i < issue_set.size(); i++){
    issue = (Issue)issue_set.get(i);
    if (organizations.contains(issue.organization)){
    }
    else{
     organizations.add(issue.organization);
    }
 }
}

void parse_buildings(){
  int i;
  Issue issue;
  for (i = 0; i < issue_set.size(); i++){
    issue = (Issue)issue_set.get(i);
    if (buildings.contains(issue.building)){
    }
    else{
     buildings.add(issue.building);
    }
 }
}

void update_iset(int d){
  // updates the iset ArrayList with those issues active up until the date specified.
  int i;
  Issue issue;
  for (i = 0; i < issue_set.size(); i++){
    issue = (Issue) issue_set.get(i);
    if (issue.open_date.equals(dates.get(d))){
      iset.add(issue);
    }
```

```
      else{
      }
    }
  }

  void update_iset_2(int d){
  // alternative to previous method
    int i;
    Issue issue;
    iset.clear();
    for (i = 0; i < d; i++){
      iset.add((Issue) issue_set.get(i));
    }
    //update_date();

  }

  void update_date(){

    Date latest_date;
    Issue issue;
    issue = (Issue) iset.get(iset.size()-1);
    latest_date = issue.open_date;

    text(format_date_string(latest_date), SLIDER_POSX, SLIDER_POSY - 20);

    //println("Latest issue date: " + latest_date.toString());

  }

  String format_date_string(Date d){

    String date_string;
    String formatted_string;
    date_string = d.toString();

    //dow mon dd hh:mm:ss zzz yyyy
    formatted_string = date_string.substring(0, 10) + " 20" + date_string.substring(24);
    return formatted_string;

  }

  void print_general_info(){
    println("| Date counter: " + date_counter + " | Date: " + dates.get(date_counter) + " |
Issues in iset: " + iset.size() + " | Total # of parsed Issues: " + issue_set.size());
```

```
  }

  void print_csv_line(String[] f) {
    // prints a parsed line from the csv file
    int i;
    for (i=0; i < f.length && i < FIELDS.length; i++) {
      println(" -> " + i + ":" + FIELDS[i] + ": " + f[i]);

    }
  }

  void update_info(){

    PImage b;
    int i, j;
    int separator = 15;
    int originx = INFO_PANEL_X;
    int originy = INFO_PANEL_Y;


    fill(255, 255, 255);

    for (i = 0; i < ORGANIZATIONS.length; i++){
      originy = originy + separator;
      if (i == 3) {
        originx = originx + 80;
        originy = INFO_PANEL_Y + separator;
      }
      text(ORGANIZATIONS[i] +": " + issue_count_per_organization(ORGANIZATIONS[i]), originx,
originy);
      for (j = 0; j < BUILDINGS.length; j++){
        originy = originy + separator;
        text("  " + BUILDINGS[j] + ": " +
issue_count_per_organization_and_building(ORGANIZATIONS[i], BUILDINGS[j]), originx, originy);
      }
    }

    originy = originy + (2*separator);
    text("Total: " + iset.size(), originx, originy);

    if (selected_issue > 0) {

      Issue issue = (Issue)iset.get(selected_issue);

      text(issue.id, ISSUE_PANEL_X, ISSUE_PANEL_Y);
      text("Date opened: " + format_date_string(issue.open_date), ISSUE_PANEL_X, ISSUE_PANEL_Y +
(separator * 1));
```

```
      text("Status: " + issue.status, ISSUE_PANEL_X, ISSUE_PANEL_Y + (separator * 2));
      text("Building: " +  issue.building + ". Level " + issue.level + ". Zone: " + issue.zone,
ISSUE_PANEL_X, ISSUE_PANEL_Y + (separator * 3));
      text("Location in grid: " + issue.x1 + ", " + issue.x2 + " / " + issue.y1 + ", " +
issue.y2, ISSUE_PANEL_X, ISSUE_PANEL_Y + (separator * 4));
      text("Discipline: " + issue.discipline + ", Trade: " + issue.trade + ". ", ISSUE_PANEL_X,
ISSUE_PANEL_Y + (separator * 5));
      text("Responsible organization: " + issue.organization, ISSUE_PANEL_X, ISSUE_PANEL_Y +
(separator * 6));
      text("Responsible person: " + issue.person, ISSUE_PANEL_X, ISSUE_PANEL_Y + (separator *
7));
      text(issue.description, ISSUE_PANEL_X, ISSUE_PANEL_Y + (separator * 8), 250, 100);
      //println("path: " + issue.imagepath.substring(issue.imagepath.length() - 9));

      if (issue.imagepath.substring(issue.imagepath.length() - 9).equals(".DS_Store")){
      }
      else{
        b = loadImage(issue.imagepath);
        image(b, 1000, 340);
        }
      //println("selected issue: " + selected_issue);
      //println("organization: " + issue.organization);
    }
  }


  String[] listFileNames(String dir) {
       File file = new File(dir);
       if (file.isDirectory()) {
        String names[] = file.list();
        return names;
       }
       else {
      // If it's not a directory
         return null;
    }
  }


  void trace(){

     println("");
     println("");
     println("No. Of Issues: " + good_issues_count);
     println("No. Of Bad Issues: " + bad_issues_count);
     println("No. of elements in ArrayList : " + issue_set.size());
     println("# of AEDAS issues: " + issue_count_per_organization("AEDAS"));
```

```
   println("# of AREP issues: " + issue_count_per_organization("AREP"));
   println("# of DDD issues: " + issue_count_per_organization("DDD"));
   println("# of ETA issues: " + issue_count_per_organization("ETA"));
   println("# of EVS issues: " + issue_count_per_organization("EVS"));
   println("# of SSJV issues: " + issue_count_per_organization("SSJV"));
}

import java.util.Date;
import java.text.SimpleDateFormat;

DateFormat dateFormat = new SimpleDateFormat("MM/dd/yyyy");

class Issue {

  boolean is_on;
  int id;
  String building;
  String level;
  String trade;
  String discipline;
  String zone;
  int x1;
  int x2;
  String y1;
  String y2;
  String description;
  Date open_date;
  String status;
  String action;
  String person;
  String organization;
  String imagepath;

  Issue (String[] values) {
    if (values[0].equals("") || values[0].length() != 5 || int(values[0]) == 0) {
      throw new IllegalArgumentException();
    }

    try {
      id = int(values[0]);
      building = values[1];
      level = values[2];
      trade = values[3];
      discipline = values[4];
      zone = values[7];
      x1 = int(values[8]);
      x2 = int(values[9]);
```

```
      y1 = values[10];
      y2 = values[11];
      description = values[14];
      open_date = parseDate(values[15]);
      status = values[16];
      action = values[19];
      person = values[20];
      organization = values[21];
      imagepath = IMAGEFOLDERPATH + "/" + IMAGES[(int)random(IMAGES.length)];
    } catch (Exception e) {
      throw new IllegalArgumentException();
    }
  }

  void update() {
  }

  String toString() {
    String r = "id: " + id + "\n";
    r += "open_date: " + open_date + "\n";
    return r;
  }

  Date parseDate(String txt) throws ParseException {
    return dateFormat.parse(txt);
  }
}
int issue_count_per_organization(String organization){
  // returns a count of the issues belinging to a specific organization
 int r, i;
 r = 0;
 Issue issue;

  for (i = 0; i < iset.size(); i++){
    issue = (Issue)iset.get(i);
    if (organization.equals(issue.organization)){
    r ++;
  }
 }
 return r;
}

int issue_count_per_organization_and_building(String organization, String building){

  int r, i;
  r= 0;
  Issue issue;
```

```
  for (i = 0; i < iset.size(); i++){
    issue = (Issue)iset.get(i);
    if ((organization.equals(issue.organization) && (building.equals(issue.building)))){
     r++;
    }
  }
  return r;
}

ArrayList issues_per_organization(String organization){

  // returns the Issues per trade

  int i;
  Issue issue;
  ArrayList r;
  r = new ArrayList();

  for (i = 0; i < iset.size(); i++){
    issue = (Issue)iset.get(i);
   if (organization.equals(issue.organization)){
     r.add(issue);
   }
  }
  return r;
}

int find_issue(String organization, int index) {
 int counter = 0;
 for (int i = 0; i < iset.size(); i++){
   Issue issue = (Issue) iset.get(i);
   if (organization.equals(issue.organization)) {
    if (counter == index) {
      return i;
    } else {
      counter++;
    }
   }
 }
 return -1;
}


void draw_rings(){
```

```
    strokeWeight(0.25);
    stroke(100);
    noFill();

    float posx, posy, posmidx, posmidy, outerposx, outerposy, innerposx1, innerposy1, innerposx2,
innerposy2, posx2, posy2, iposx, iposy;
    float bposx, bposy, bposmidx, bposmidy, outerposmidx, outerposmidy;
    int internal_radius, middle_radius;
    int i, j, k, l;
    int issues_per_organization;
    int issues_per_organization_and_building;
    float theta, phi, phi_mid, theta_mid, gamma, test_factor, sigma;
    float increment, small_increment, building_increment, outer_increment;

    internal_radius = RAD_INNER/2;
    middle_radius = RAD_MID/2;

    increment = 0;
    building_increment = 0;
    theta = 2*PI;
    phi = 2*PI;
    gamma = 2*PI;
    sigma = 2*PI;
    test_factor = 0;

    float[] organization_ratios = new float[ORGANIZATIONS.length];
    float[] building_ratios = new float[BUILDINGS.length];

    // DRAW RINGS

    // OUTER ELLIPSE
    ellipse(CENTERX, CENTERY, RAD, RAD);

    // MIDDLE ELLIPSE
    ellipse(CENTERX, CENTERY, RAD_MID, RAD_MID);

    // INNER ELLIPSE
    ellipse(CENTERX, CENTERY, RAD_INNER, RAD_INNER);

    strokeWeight(0.75);

    // inner ring: organizations
    for (i = 0; i < 6; i++){

      // define the proportions of the circle for defining the organization
      organization_ratios[i] = (float)issue_count_per_organization(ORGANIZATIONS[i])/iset.size();
      issues_per_organization = issue_count_per_organization(ORGANIZATIONS[i]);
```

```
      // find angle boundaries for organization on inner ring
      theta = 2*PI*(organization_ratios[i]+increment);
      theta_mid = 2*PI*((organization_ratios[i]/2)+increment);

      // points on inner ring
      posx = CENTERX + (cos(theta)*internal_radius);
      posy = CENTERY - (sin(theta)*internal_radius);

      // points on middle ring
      posx2 = CENTERX + (cos(theta)*middle_radius);
      posy2 = CENTERY - (sin(theta)*middle_radius);

      // middle (branch) points on inner ring
      posmidx = CENTERX + (cos(theta_mid)*internal_radius);
      posmidy = CENTERY - (sin(theta_mid)*internal_radius);

      // middle (branch) points for bezier control
      outerposmidx = CENTERX + (cos(theta_mid)*(internal_radius + 50));
      outerposmidy = CENTERY - (sin(theta_mid)*(internal_radius + 50));

      // draw organization bounding points
      stroke(0, 0, 255);
      strokeWeight(0.45);
      //ellipse(posx, posy, 5, 5);
      //ellipse(outerposmidx, outerposmidy, 20, 20);
      //line (posx2, posy2, CENTERX, CENTERY);
      stroke(255, 0, 0);
      rect(posmidx-3, posmidy-3, 6, 6);
      line(CENTERX, CENTERY, posmidx, posmidy);
      text(ORGANIZATIONS[i], posmidx + 10, posmidy + 10);

      phi = theta;

      // middle ring: buildings
      for (l = 0; l < 5; l++){ // for each building in an organization

        // starting angle
        issues_per_organization_and_building =
issue_count_per_organization_and_building(ORGANIZATIONS[i], (String) BUILDINGS[l]);
        building_ratios[l] = (float) issues_per_organization_and_building/iset.size();

        // find angle boundaries for organization on inner ring
        phi = 2*PI*(building_ratios[l] + building_increment);
        phi_mid = 2*PI*((building_ratios[l]/2) + building_increment);

        bposx = CENTERX + (cos(phi)*middle_radius);
```

```
        bposy = CENTERY - (sin(phi)*middle_radius);

        // middle poings on middle ring

        bposmidx = CENTERX + (cos(phi_mid) * middle_radius);
        bposmidy = CENTERY - (sin(phi_mid) * middle_radius);

        // draw organization bounding points
        stroke(255, 0, 255);
        strokeWeight(1);
        if (issues_per_organization_and_building > 0){ // only draw branch if there are issues
          line(bposmidx, bposmidy, posmidx, posmidy);
          stroke(0,0,255);
          strokeWeight(0.45);
          //ellipse(bposx, bposy, 5, 5);
          stroke(255, 0, 255);
          strokeWeight(0.7);
          rect(bposmidx-3, bposmidy-3, 6, 6);
          text((String) buildings.get(l), bposmidx + 10, bposmidy + 10);
        }




        //if (viz_mode == 0){

          for (k = 0; k < issues_per_organization_and_building; k++){

            // angle
            sigma = 2*PI*(((building_ratios[l]/issues_per_organization_and_building)*k) +
building_increment);

            // position
            iposx = CENTERX + (cos(sigma)*RAD/2);
            iposy = CENTERY - (sin(sigma)*RAD/2);

            // drawing
            strokeWeight(0.1);
            stroke(colors_buildings[l]);
            //ellipse(iposx, iposy, 3, 3);
            //strokeWeight(0.1);

            //  LINE **** NEEDS TO BE SPLINE
            line(bposmidx, bposmidy, iposx, iposy);


          }
```

```
          building_increment = building_increment + building_ratios[1];

        //}

      }


      // draw all issues in outer ring
      boolean found_pick = false;

      for (j = 0; j < issues_per_organization; j++){

        gamma = 2 * PI * (((organization_ratios[i] / issues_per_organization) * j) + increment);

        posx = CENTERX + (cos(gamma)*RAD/2);
        posy = CENTERY - (sin(gamma)*RAD/2);

        // bezier control geometry
        outerposx = CENTERX + (cos(gamma)*((RAD/2)-50));
        outerposy = CENTERY - (sin(gamma)*((RAD/2)-50));

        //innerposx1 = CENTERX + (cos(gamma)*(middle_radius-(SEPARATION/2)+20));
        //innerposy1 = CENTERY - (sin(gamma)*(middle_radius-(SEPARATION/2)+20));

        //innerposx2 = CENTERX + (cos(gamma)*(middle_radius-SEPARATION));
        //innerposy2 = CENTERY - (sin(gamma)*(middle_radius-SEPARATION));

        // outer construction line
        //line (posx, posy, outerposx, outerposy);

        // BEZIER

        // draw bezier to pick buffer with an color that encondes the id of the issue

        color id = color(i, j, 0);

        pick_buffer.beginDraw();
        pick_buffer.stroke(id);
        pick_buffer.bezier(posx, posy, outerposx, outerposy, outerposmidx, outerposmidy, posmidx,
posmidy);
        pick_buffer.endDraw();

        // is the mouse over a pixel with the same id?

        color value = pick_buffer.get(mouseX, mouseY);
```

```
        if (value == id && !found_pick) {
          stroke(255, 0, 0);
          found_pick = true;
          selected_issue = find_issue(ORGANIZATIONS[i], j);
        } else {
          //strokeWeight(1);
          stroke(0,255,0);
        }

        strokeWeight(0.25);

        // older beziers

        if (petal_switch == 1){
          //bezier(posmidx, posmidy, CENTERX, CENTERY, outerposx, outerposy, posx, posy);

          // petals
          //bezier(posx, posy, CENTERX, CENTERY, outerposx, outerposy, posmidx, posmidy);
          //bezier(posx, posy, outerposx, outerposy, innerposx1, innerposy1, innerposx2,
innerposy2);

          // well formed bezier: draw to main canvas
          stroke(colors_organizations[i]);
          bezier(posx, posy, outerposx, outerposy, outerposmidx, outerposmidy, posmidx, posmidy);
        }
        else{

        }


      }


      increment = increment + organization_ratios[i];
    }
  }



  void make_gui(){

       cp5 = new ControlP5(this);

    myKnobA = cp5.addKnob("radius_a")
                 .setRange(300,900)
                 .setValue(RAD)
                 .setPosition(KNOBS_X,KNOBS_Y)
```

```
             .setRadius(KNOB_RADIUS)
             .setViewStyle(Knob.ARC)
             .setColorForeground(color(100,100,100))
             .setColorBackground(color(20, 20, 20))
             .setColorActive(color(30,30,30))
             .setDragDirection(Knob.HORIZONTAL)
             ;

myKnobB = cp5.addKnob("radius_b")
             .setRange(300,1000)
             .setValue(RAD_MID)
             .setPosition(KNOBS_X + KNOB_SEPARATION, KNOBS_Y)
             .setRadius(KNOB_RADIUS)
             .setViewStyle(Knob.ARC)
             .setColorForeground(color(100,100,100))
             .setColorBackground(color(20, 20, 20))
             .setColorActive(color(30,30,30))
             .setDragDirection(Knob.HORIZONTAL)
             ;

myKnobB = cp5.addKnob("radius_c")
             .setRange(50,900)
             .setValue(RAD_INNER)
             .setPosition(KNOBS_X + (KNOB_SEPARATION*2), KNOBS_Y)
             .setRadius(KNOB_RADIUS)
             .setViewStyle(Knob.ARC)
             .setColorForeground(color(100,100,100))
             .setColorBackground(color(20, 20, 20))
             .setColorActive(color(30,30,30))
             .setDragDirection(Knob.HORIZONTAL)
             ;

cp5.addSlider("dates")
   //.setFont(font)
   .setPosition(SLIDER_POSX, SLIDER_POSY)
   .setRange(0,255)
   .setNumberOfTickMarks(dates.size())
   .setWidth(SLIDER_WIDTH)
   .showTickMarks(true)
   .snapToTickMarks(true)
   .setMin(0)
   .setMax(issue_set.size())
   //.setMax(dates.size()-1)
   .setColorActive(100)
   .setColorBackground(255)
   .setColorForeground(200)
   ;
```

```
  cp5.getController("radius_a")
     .getCaptionLabel()
     .setFont(font)
     .toUpperCase(false)
     .setSize(10)
     ;

  cp5.getController("radius_b")
     .getCaptionLabel()
     .setFont(font)
     .toUpperCase(false)
     .setSize(10)
     ;

  cp5.getController("radius_c")
     .getCaptionLabel()
     .setFont(font)
     .toUpperCase(false)
     .setSize(10)
     ;


  cb = cp5.addCheckBox("checkBox")
      .setPosition(KNOBS_X, KNOBS_Y - 20)
      .setColorForeground(color(0))
      .setColorBackground(40)
      .setColorActive(color(255))
      .setColorLabel(color(255))
      .setSize(10, 10)
      .setItemsPerRow(3)
      .setSpacingColumn(20)
      .setSpacingRow(5)
      .addItem("PS", 0)
      .addItem("TR", 1)
      //.addItem("100", 100)
      //.addItem("150", 150)
      //.addItem("200", 200)
      //.addItem("255", 255)
      ;
}


void keyPressed() {
  if (key==' ') {
    cb.deactivateAll();
  }
```

```
  else {
    for (int i=0;i<6;i++) {
      // check if key 0-5 have been pressed and toggle
      // the checkbox item accordingly.
      if (keyCode==(48 + i)) {
        // the index of checkbox items start at 0
        cb.toggle(i);
        println("toggle "+cb.getItem(i).name());
        // also see
        // checkbox.activate(index);
        // checkbox.deactivate(index);
      }
    }
  }
}

void radius_a(int theValue) {
  //knob a
  //myColorBackground = color(theValue);
  RAD = theValue;
  //println("a knob event: "+theValue);
}

void radius_b(int theValue) {
  //knob b
  //myColorBackground = color(theValue);
  RAD_MID = theValue;
  //println("a knob event: "+theValue);
}

void radius_c(int theValue){
//knob c
  RAD_INNER = theValue;
}

void dates(float value) {
  update_iset_2((int) value);
}

void controlEvent(ControlEvent theEvent) {
  if (theEvent.isFrom(cb)) {

    petal_switch = (int) cb.getArrayValue()[0];
    tree_switch = (int) cb.getArrayValue()[1];
    }
}
```

```
void checkBox(float[] a) {
  println(a);
}
```

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