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The Active Image

Architecture and Engineering in the Age of Modeling

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Chapter 2
Architecture and the Structured Image: Software Simulations as Infrastructures for Building Production

Daniel Cardoso Llach

Never underestimate the power of a widely distributed tool.

—John Walker[1]

Abstract This chapter shows how technical and conceptual innovations brought about by Computer-Aided Design (CAD) research during the 1960s and 1970s foreshadow current practices of building design and construction, and are foundational to a modern epistemology of the image in the age of simulation. No longer construed as pictorial representations of a design but rather as mathematically enlivened and operative artifacts performing it, computationally produced images elicited new aesthetic and managerial aspirations—crucially, to re-structure design labor and to destabilize the boundaries between design and construction. Interrogating the material and discursive tenets of this transformation through both historical evidence and ethnographic insight, the chapter proposes the analytical category of "structured image" to engage with its significance to architectural and visual cultures. It further proposes that the scale at which this reconfiguration is realized requires both historically informed perspectives and performative, localized accounts of socio-technical practice.

Keywords Computer-Aided Design (CAD) • Building Information Modeling (BIM) • Architecture • Science, Technology and Society (STS) • Design, Technology and Society

In *Image and Logic*, historian of science Peter Galison writes about a new mode of coordinating activities emerging in the aftermath of the Second World War, where "scientists from different disciplines (different practice and language groups) could form a trading zone" (Galison 1997: 153). He observed how simulations allowed people of different backgrounds to collaborate without sharing a common language,

[1] John Walker the chairman of Autodesk, the software company that developed AutoCAD, between 1982 and 1986 (Walker (Ed.) 1989: 300).

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and prompted the formation of a new field of technical expertise. In modern practices of building design and construction, a growing consensus aspires to realize a similar mode of collaboration. This ambition coalesces today around the technology project known as Building Information Modeling (BIM): the use of highly detailed building simulations to centralize building design and construction coordination, reorganizing multiple trade and professional groups around a highly-detailed digital model and its associated protocols of information production and exchange.[2]

To offer a portrait of BIM that opens this ambition to critical examination, this chapter threads through primary archival and ethnographic sources and takes distance from a dominant narrative of BIM as the universal future for building design and construction. Instead, it situates it within the landscape of technological and discursive production of Cold War era military-funded research projects in the United States, and respecifies it as the expression of an infrastructural project to reorganize the worlds of architectural and building practice around managerial efficiency and control.

However, this is an infrastructure still in the making. Technological discourses often present desired outcomes as factual accounts, and possible futures as inevitable. To avoid these critical blind spots, we might ask what perspectives and voices—what other futures—are obscured by such discourses. By respecifying BIM as a sociotechnical proposition this chapter reveals how it is irreducibly contingent upon multiple social, material, and technical rearrangements. As we shall see, in order to participate in the trading zones of BIM, relevant actors must commit to visual, technical, and organizational epistemologies whose deployment and adoption is neither seamless nor universal. A thesis of this chapter is that while the practices of building simulation that coalesce under the BIM rubric inscribe an infrastructural ambition to reorganize worlds of practice, they also engender creative forms of resistance.

A second thesis has to do with method. Enabled by increasingly intricate sociotechnical systems comprising humans, machines, software, as well as cultural and legal protocols, modern building production poses critical challenges that demand both historically-informed and localized, performative accounts of technological practice. Confronting the scale and scope of these challenges, studies of design, technology, and society—the field of inquiry I seek to circumscribe—may focus on examining dominant technological discourses and narratives against these localized accounts to reveal the seams, the uneven distributions, and the messy encounters such discourses often obscure.

[2] Architect and BIM advocate Randy Deutsch provides a concise definition of BIM: "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" (Deutsch 2011; see also Bergin 2015).

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2.1 From Picture to Artifact: The Rise of the Structured Image

Despite its apparent novelty, the technical and conceptual origins of Building Information Modeling can be traced back to the Cold War era's research and development projects within what is often termed, after Eisenhower, the US "military-industrial-academic complex" (1961). Crucial for our analysis, the key precursor to BIM was the wartime development of a new kind of image linked to the new computing technologies for data storage, manipulation, and display. First experienced on the screens of radar systems displaying maps and associated information, this new image was produced by a computer's processing of numerical information describing geometric point coordinates of line segments. Encoded in punched cards, these numerical definitions were translated into signals controlling the way a stream of electrons fell onto the phosphorous inside of a cathode ray tube display, thus rendering the image. Emblematic of this era, the SAGE (Semi-Automated Ground Environment) defense system, launched in 1951, used radar technologies to track enemy airplanes and display maps with the position of the planes on cathode ray tube monitors (Fig. 2.1). Besides the characteristic glow of these early displays, what distinguished this image from its ink and paper relatives was a fundamental separation between the image itself (as rendered on the screen) and the numerical

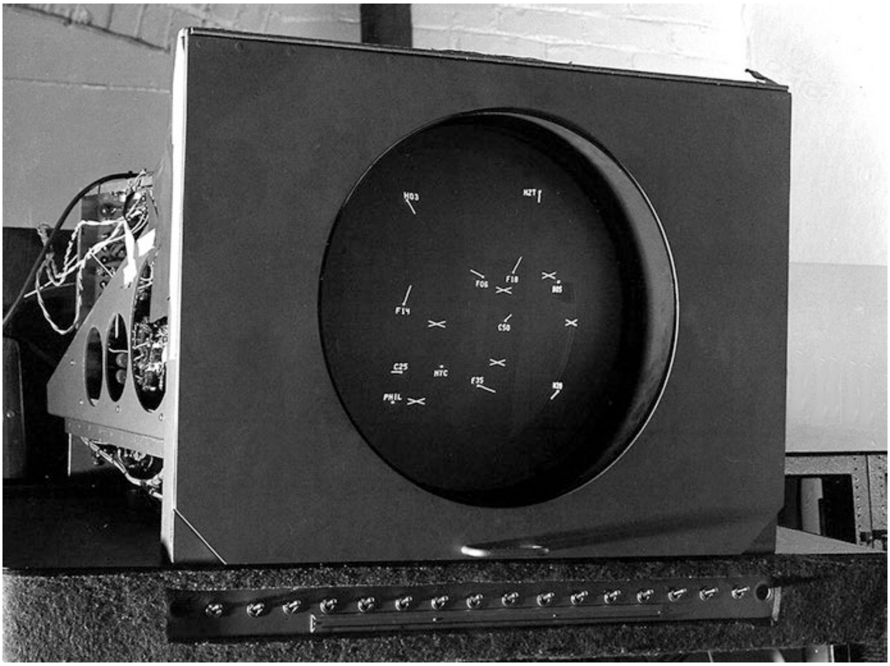

Fig. 2.1 Semi-Automated Ground Environment (SAGE) (MITRE Corporation. Photograph is used and reprinted with permission of The MITRE Corporation © 2015. All other rights reserved)

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information behind it (as inscribed in storage media such as punched cards). In contrast with images produced using traditional methods such as pencil and ink on paper, computer-generated images resulted from a continuous and semi-automatic process of translation between numerical definitions inscribed in a storage medium (software) and a rendering system (hardware).

This split between the visible image and its encoded numerical definition inscribes a technical dissociation with profound implications for our analysis: the dissociation between the punched card and the radar screen—between symbolic, non-pictorial information and the electro-mechanical computing systems rendering the image. At a rate of several dozen translations per second between the symbolic definitions inscribed in software and the images rendered on the screen, these *structured* images prompted Cold War era's researchers to imagine new ways of going about designing, representating, and manufacturing.

From the Latin voice *struere*, to build, the word structure conveys the tectonic mindset that shaped image-making practices in the age of computing. For most architects, a building's structure is the collection of underlying material elements making it stable and robust. In many buildings, these structural elements—columns, beams, bearing walls—are hidden from view, masked by non-structural architectural elements such as cladding and fixtures. In fact, the relationship between structure and space has long been a subject in architecture studies, brokered in part by a modernist emphasis on the affordances of industrially-produced construction materials, such as steel and glass, to *separate* spatial and structural form. In formulating the analytical category of "structured image," we may usefully consider how a comparable separation took place in the discourses of image production that accompanied the emergence of computational media. References to the "structure" of computer drawings and its affordances pepper the discourses of the early Computer-Aided Design (CAD) pioneers. Likening images to built artifacts, Cold War era's engineers and mathematicians reframed images as artifacts to be *engineered*: clad onto their underlying numerical structures, computer images were to enable a design process seamlessly linked to analysis, manufacturing and logistics. Detached from their pictorial character, the structured image was conceptualized as a simulation (not a representation) of a design.[3] My emphasis here is on simulations' performative character: invoking the word's connotation as "theatrical" and "deceptive," we can usefully see software simulations as staged

[3] For example, Computer-Aided Design (CAD) pioneer Ivan Sutherland articulated the separation between structure and image with remarkable clarity (Sutherland 1975: 73–77). Computer Art pioneer Frieder Nake (2013) has also discussed it, retrospectively. For an extended discussion about early discourses of image-making during the early days of CAD, see Daniel Cardoso Llach (2013, 2015b). My use of simulations here aligns with Loukissas' notion of these systems as "composed of theories, material processes, mathematical artifacts, and interpretations" the meanings of which are contingent upon the actors and practices they link (Loukissas 2012).

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performances where the computer image, enlivened via its structure, *represents* in a distinctive way.[4]

The first systematic exploration of the possibilities of the structured image for design and manufacturing can be traced back to the Computer-Aided Design (CAD) Project, a research operation funded by the United States Air Force at the Massachusetts Institute of Technology (MIT) between 1959 and 1970.[5] A joint effort combining faculty and students of the electrical and mechanical engineering departments at MIT, the CAD Project sought to take advantage of recent advances in servomechanisms, time-sharing, numerically controlled machinery and cathode ray tube monitors for aiding design and manufacturing processes. Besides coining the phrase "Computer-Aided Design," CAD Project members were responsible for developing or laying the foundations for numerous innovations including interactive graphical communication, 3-D computer graphics, computer-vision, and object oriented programming languages.[6] Under the advice of Steve A. Coons, one of the project's leaders, Ivan Sutherland developed the first interactive graphics program, called "Sketchpad," as part of his Ph.D. thesis in electrical engineering at MIT in 1964.[7] Sketchpad allowed a user to draw on a 9-inch CRT monitor with a light pen and to transform the drawing using a variety of commands (Sutherland 1963).

As I discuss at length elsewhere, besides their remarkable technical achievements, members of this group were also design *theorists* who reimagined design in computational terms (Cardoso Llach 2015a, b: 149). Under the influence of contemporary discourses about cybernetics and Artificial Intelligence, CAD Project members imagined that design could be described computationally as an iterative process of representation, analysis and manufacturing, where computers took care of the drudgery of mechanical and analytical work while humans devoted their time to more "creative" endeavors.[8] Crucial to our analysis, the themes of seamless collaboration in design via computer simulations populating today's discourses about BIM were laid out during this period of remarkable inventiveness. The engineers and technologists leading the CAD Project, prominently Steven A. Coons and Douglas T. Ross, saw in the "structured" character of the computational image an opportunity to reimagine design and construction practices as the manipulation of interconnected bundles of information (instead of as the manual production of physical drawings and artifacts). The programming languages they developed to communicate

[4] See Loukissas (2012).

[5] This is illustrated by Douglas Ross's work on language development for numerical control dating back to the early 1950s. For an extended discussion about the early days of numerical control see Daniel Cardoso Llach (2015b).

[6] An early formulation of computer vision can be found in Lawrence G. Roberts, and Peter Elias (1963).

[7] While independently funded, Sutherland worked under the advice of CAD Project co-director Steven A. Coons.

[8] For influential formulations of cybernetics see Wiener (1965), and Licklider (1960).

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with milling machines and oscilloscopes constituted a kind of neutral, intermediary space where information pertaining to geometric, graphic, technical, and material aspects of a design could be inscribed, manipulated, and shared (Cardoso Llach 2015b). For example, in a computer-generated image of a house, the CAD Project engineers realized that a door could be described with information about its shape but *also* about its material, cost, structural properties, and other attributes.[9] A concrete beam could be described with information such as length and height, but the same data structure could be furnished with information about its structural behavior. These structured images, they understood, could enable designers to instantly perform structural and cost analysis, and could be made available to different parties for coordination. It is in this precise sense that we can talk about the postwar rise of a new, *structured*, image marking the origins of what is today known as BIM. As we shall see, the structured image is the technical and conceptual fulcrum of our modern understanding of building design and construction.[10]

Often dismissed as the work of mere technicians automating conventional drafting practices (and thus irrelevant to discussions in architecture studies), the early work of CAD researchers in fact inscribes a profound theoretical reconfiguration of design and construction as data-centric practices. In the intermediary spaces of software, and in the new affordances of the structured image, the early days of CAD illustrate how simulations were always imagined as infrastructures enabling collaborative work. We might also see them as expressions of a colonizing impulse typical of computing cultures: in the computer, CAD researchers saw a new disciplinary territory they could claim as their own by encoding and thus displacing traditional design practices.[11] The earliest CAD innovations were in fact premised on a rhetorical rejection of drafting and on the adoption of a new epistemology of design representation construing images as engineered *artifacts*.[12] As Ivan Sutherland himself explained, somewhat dismissively: compared to computer images, drawings made by hand have no *structure*; they are only "dirty marks on paper" (Sutherland 1975, italics are mine).

Prompting visions of a seamless process from conception to manufacturing, the view of design that accompanied the rise of the structured image made its way into

[9] During the late 1960s until the late 1970s, this line of work was further developed and enriched at the University of Cambridge, UK, by a group of researchers including CAD Project alum Charles Lang, Ian Braid and others. The academic researcher Charles Eastman spearheaded these efforts in the US (Cardoso Llach 2015b: 87).

[10] The vision of design by the CAD Project engineers is linked to then contemporary cybernetic discourses. A particularly articulate vision of architectural work with computers is outlined by computer pioneer Douglas Engelbart in 1962, which starts with a suggestive "Let us consider an augmented architect at work (…)" (Engelbart 1962); see also Licklider (1960).

[11] The terms of this redefinition and colonization were the subject of important debates among CAD researchers (Cardoso Llach 2015b: 149).

[12] I have called this particular notion of design based on structured representations an "algorithmic tectonics" (Cardoso Llach 2013).

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discourses about architecture and construction, transforming professional boundaries, creating new social roles, and new ways of thinking about designing and building—ultimately underpinning a multi-billion software industry. Whether the image's structure is encoded in punched cards, as in the early days of CAD research, in solid-state hard drives or in distant servers, the fundamental separation between an image and its (computable, numerical and non-pictorial) structure remains the distinctive feature of images in the computing age. These technical and conceptual innovations are not only key precursors to contemporary practices of building production, but also foundational to a contemporary epistemology of the image in the age of simulation.

2.2 Infrastructural Ambitions

Despite these researchers' ambitious drive to reconfigure a wide array of design and construction practices, the CAD software industry evolved in a different direction and came to be dominated by software packages that offered more modest advancements such as the automation of manual drafting procedures.[13] It was only until the 1990s that the technology project we now identify as BIM reactivated the goals of data-rich 3-D representations and links to manufacturing set forth by the early CAD proponents.[14] A series of technical advancements made this reappearance possible: increased speed of graphics hardware and processors made software capable of managing larger amounts of data, enabling users to create and manipulate highly detailed 3-D models; mathematical advancements in computational geometry coming from the aircraft and car manufacturing industry made their way into consumer software packages, affording designers greater control over the definition and manipulation of digital three-dimensional models of surfaces and solids; a fledgling internet made the prospect of seamless, transnational forms of collaborative work somewhat more credible. Furthermore, economic demands for greater quantities of (and precision in) building documentation fueled a desire for more powerful and ever more connected work environments.

Resting on these technical supports and fueled by the late twentieth century's economic and cultural climate, the BIM project appears to give global amplitude to the ambition of combining computing, management and rhetoric to reorganize what is in fact a vastly diverse landscape of design and manufacturing practices—an

[13] Commercial CAD systems such as AutoCAD and MicroStation dominated the market for decades. For detailed industry accounts, see Kristine K. Fallon (1997), David E. Weisberg (2008), and John Walker (1989). For historical perspectives on architect's adoption of CAD see Robert Bruegmann (1989), and Alfredo Andia (2002). For a key source of ethnographic and historical insight regarding the CAD industry during the 1980s and 1990s see Allen B. Downey (2012).

[14] The software Archicad, by Graphisoft, is often credited with spearheading this transition.

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ambition to be *infrastructural*. Accordingly, involving both software and a reconfigured ecology of building practices, the BIM project cannot be accurately described as a tool (a term that evokes the intimacy of an individual working with an instrument on a material) but rather as an infrastructure. The scale and scope of its ambition is to channel and regiment the production and circulation of information across a complex of individuals and organizations, radically transforming the building industry's socio-technical dynamics.

Accordingly, the development of strict protocols of information, production, manipulation, and exchange, and the inscription of these protocols in software systems, workflows, and digital formats are at the root of the BIM. As we shall see, the project of making this vision a reality is in fact a very large socio-technical effort—not unlike the development of other large infrastructural projects, such as railroads or telegraph lines. A shift of perspective is in order.

2.3 Seeking a *Lingua Franca*: Standardizing the Structured Image

Despite technologists' visions of a seamless process of building design and construction enabled by simulations, making a building remains a distinctively messy affair, contingent upon multiple social, technical, and material factors. In contrast with the aircraft and car manufacturing industries, where economies of scale allow for the concentration of most design and production along serialized and (relatively) manageable production processes, building design and construction involves a more disperse and frequently unruly landscape of trades and industries, each with their own cultural and technological idiosyncrasies. A professional or trade group may forge an identity mainly through a distinctive technical jargon and shared training, but frequently also through technological literacies that often comprise trade-specific software systems, and their particular cultures of representation and work.[15] The dominant BIM narrative normatively construes this diversity as a source of inefficiency—as something to be optimized away through computerized standardization. A report by the US National Institute of Standards (NIST) helps illustrate this common rationalization for the advancement of BIM. A single universal BIM format, the report argues, will reduce "redundant data entry, redundant IT systems and IT staff, inefficient business processes, and delays indirectly resulting from those efficiencies" (Gallaher et al. 2004, Laakso and Kiviniemi 2012: 136). The report estimates the yearly benefits resulting from the adoption of a common BIM standard at a remarkable $15.8 billion. It is worth noting, however, that architects,

[15] Yanni Loukissas (2008) has shown how professionals use simulations to create distinct professional identities.

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engineers, contractors, laborers, and fabricators are not the main beneficiaries of these projections, which chiefly privilege owners and operators.

To accomplish the managerial efficiencies promised by such discourses, images need not only be structured, but also comply with standards making them readable by different systems and applications. A single standard would reduce the problems derived from a lack of compatibility between the many different proprietary formats used by different trades and professional groups. For its proponents, such Esperanto of building holds the promise of enabling easy communication across disciplines, and a "seamless flow of design, cost, project, production and maintenance information, thereby reducing redundancy and increasing efficiency throughout the lifecycle of the building" (Laakso and Kiviniemi 2012: 135, Björk and Laakso 2010, Howard and Björk 2008). The combined efforts by academics, industry consortia, professionals, and other actors to establish a single digital standard—a format—as a *lingua franca* for design and construction information illustrate the infrastructural scale and universalist ambition of the BIM project.

The first attempt at creating a standard digital format for 3-D geometry dates back to 1979. A joint venture between Boeing, General Electric, and Xerox, with the US Department of Defense, created the first version of the Initial Graphics Exchange Specification (IGES) format, which was officially released in 1980 by the American National Standards Institute (ANSI) and was never widely adopted by the industry (see National Bureau of Standards 1988, Björk and Laakso 2010). Instead, Autodesk's proprietary format DWG (for Drawing) became the *de facto* standard for digital files as a result of AutoCAD's dominance over the market. In contrast with IGES, which was an open format, DWG was "closed," so its specifications were not available to the public.[16] Preceding these efforts were the attempts, starting in the 1960s, to turn an early language for controlling milling machines, Automated Programming Tool (APT), into an industry standard. Resulting from a joint effort between engineers at the Servomechanisms Laboratory at MIT, the US Air Force, and numerous aircraft companies, APT was in fact recognized as a standard for the aircraft industry in 1978 (Cardoso Llach 2015b: 42).

More specific to building design, a softer form of standardization was used among CAD users in offices and firms in the US and Western Europe since the 1980s. The use of color codes for different "layers" in a drawing file helped architectural practitioners organize and read distinct "families" of architectural elements separated visually.[17] This "soft" standardization of aspects of drawing production facilitated the collaboration across different organizations. In some cases, color

[16] 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.

[17] 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 (1997: 78).

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codes for CAD layers were formalized into regional (and national) norms.[18] However, proponents of this approach complained that a lack of resources for marketing and training prevented it from becoming an effective industry standard (Howard and Björk 2007).

Perhaps the most notable effort towards an open industry standard is the ongoing development of the Industry Foundation Classes (IFC) file format. Designed as an "open" standard without ties to particular companies or software vendors, its developers describe it as "a common data schema that makes it possible to hold and exchange data between different proprietary software applications. The data schema—another way of calling the file's data-structure—comprises information about 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 2008). An object-oriented representation of architectural elements, the IFC format is equipped with specific handlers for architectural elements such as beams, walls, doors, to which relevant information, such as cost and performance data, can be associated as attributes. For example, a designer can specify a door geometrically, but also with attributes such as model, fabricator, cost, and other supply-chain information.

The origins of IFC can be traced to the Standards for the Exchange of Product Data (STEP) project by the International Standards Organization (ISO) started in 1985. STEP laid the foundations of what a decade later would become the Industry Alliance for Interoperability (IAI),[19] an effort towards standardization led by a group of 12 American companies using AutoCAD—Autodesk, the company behind AutoCAD, had in fact a founding role in the IAI. Since its foundation in the 1990s, the IAI—later called BuildingSMART—is the international body in charge of developing, promoting, and implementing IFC standardization. This organization released the first version of the IFC format in 1997 with the goal of making a platform-independent standard for international use (Howard and Björk 2008). While construed as a global effort, it is worth noting that the companies comprising the BuildingSMART consortium are all Anglo-American or British (BuildingSMART 2015).

IFC proponents highlight the format's virtues of openness and independency from software vendors. However, its adoption outside academia has been very slow (Howard and Björk 2008: 18). Unsurprisingly, members of different disciplines have different inclinations and opinions about what should be standardized, and many believe that the ISO should refrain from developing an open standard and simply formalize the *de facto* standard as reflected by the market—just as Autodesk's DWG became a *de facto* standard for CAD in the 1980s (ibid). However, the IFC standard continues to be developed and sustained by an academic interest on open-

[18] A standard for layer coloring was formalized by the ISO (International Organization for Standardization 1998).

[19] The IAI was renamed to International Alliance for Interoperability in 1997 and to BuildingSMART in 2015 (Eastman et al. 2011: 72).

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ness, by industry actors concerned with the problematic consequences of making a proprietary format an international standard, and by the impact of governmental regulations mandating the implementation of such open standards in the building industry.

Despite the alignment of these forces, the wide use of proprietary software systems such as Autodesk's Revit and their proprietary file formats will likely make them the *de facto* standards of work and information exchange in large portions of the industry, with IFC becoming in many cases a legal requirement—and in others, a useful sandbox for experimentation and speculative thinking about the building industry in academic and industry research circles.

2.4 Representations of BIM

Consistent with its ambition to reorganize a diverse landscape of building design and construction practices, stereotypical representations of BIM depict it as a radial array of trades connected to the digital model, located at the center (Fig. 2.2). In this

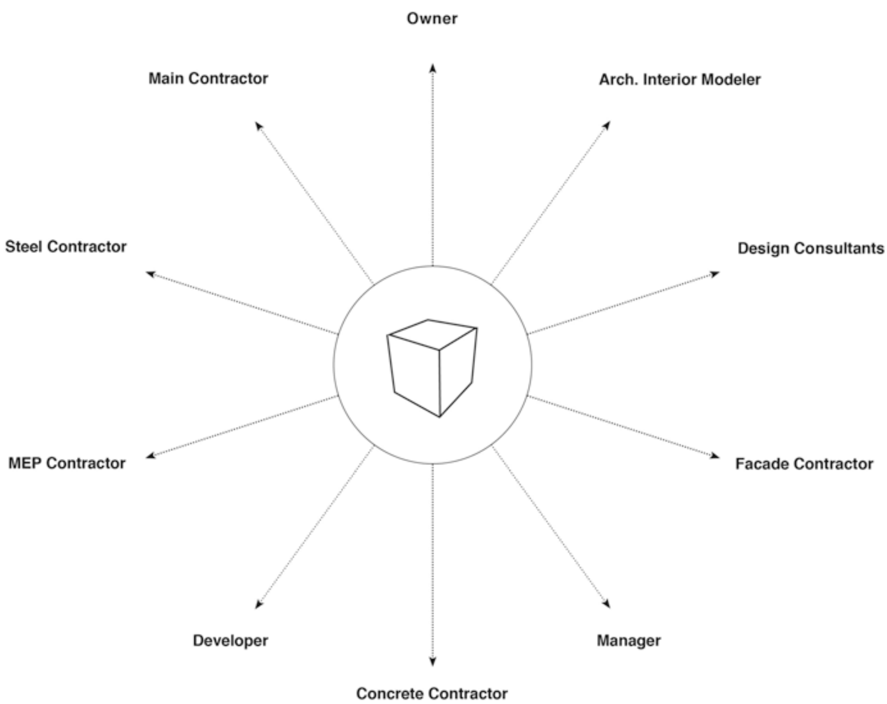

Fig. 2.2 Common representation of Building Information Modeling depicting the building industry as a ring of trades arranged around a central digital model (Image by author)

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diagram, the contractual, but also the social and cultural hierarchies of design and construction are flattened: clients, architects, and trade organizations are portrayed as equal tributaries to a central digital model. Also important, the lines connecting the digital model to each actor are symbolic of presumed seamless connections between industries traditionally separated by their different professional (and technological) idiosyncrasies. These lines are sometimes explicitly referred to as “pipes” for design information to circulate (Shelden 2010). Obviously the “pipe” metaphor hints at the infrastructural ambition of the BIM project in its simplest disclosure as a physical system enabling material flows.

Following Lucy Suchman, technological narratives constitute a “proposition for a geography within which relevant subjects and objects may claim their place” (Suchman 2006). Placing the digital model at the *center* of design and construction practices, this pervasive narrative of BIM has power to shape disciplinary and popular expectations about what it means to design and build. How may we begin to examine this centrality? As historians of science and STS scholars have persuasively shown, technologies are always social as their conception, development and operation inevitably comprises individuals, organizations, as well as shared modes of communication and work.

The development of the BIM infrastructure is not exclusively the pursuit of technologists but it also involves software vendors, academics, authors, technology proselytizers, industry consortia, government, engineers, journalists, students, and architects. One of the project’s key proponents, for example, is the prominent United States architect Frank Gehry, who adopts a typically optimistic view of computers and describes BIM as a means for architects to exert greater control over a building’s design and construction—returning architects to being Renaissance master builders (Gehry 2011). Gehry has gathered the support of other prominent architects—including Zaha Hadid and Jean Nouvel among many others—for the approach to building his firm enacts. Somewhat ironically, Gehry has played an important role in placing BIM at the center of a vibrant debate in industry and academia about the role computing may play in architectural practice, despite not using computers himself.[20]

Contrary to Gehry’s optimistic view of BIM as an empowering tool for architects—which is increasingly shared by his colleagues—in the hands of developers, contractors, and clients, BIM is frequently presented in a different light, as a way to reduce the role (and fees) of the architect in building production to that of just another consultant (Wallbank 2011). Aligned with larger forces shaping architectural production in the US towards increasingly corporate models of practice (Gutman 1997: 78), the efficiencies BIM promises mostly benefit owners and devel-

[20] According to the press release “the alliance intends to enable new approaches to design through technology, to create more effective industry processes and a higher quality built environment. By applying and innovating new technology solutions to old problems such as waste, delay, and miscommunication, this new alliance will lead the process change that the AEC industry needs to confront future challenges. The group represents a new type of professional organization for the twenty-first century, one which embraces the possibility of technology to empower design” (Gehry Technologies 2011; Minner 2011).

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opers—as mentioned above. In the meantime, BIM has increasingly made it into public policy. For example, the General Services Administration in the United States established an official program to promote the implementation of three and four-dimensional BIM modeling practices in the public sector. Similar governmental regulations request BIM across several countries in Europe and Asia.[21]

Meanwhile, other actors contribute to endowing BIM with an aura of historical inevitability. As we saw, industry consortia seek to standardize digital formats and practices to facilitate information sharing and to reduce costs derived from "interoperability conflicts" between different industry actors (see for instance Björk and Laakso 2010). Software companies and vendors seek market dominance by establishing proprietary *de facto* standard formats while aggressively partnering with academic institutions and firms (Appelbaum 2009; Arieff 2013; Autodesk 2013; Carfrae 2011). Academics in architecture, engineering, and construction management programs disseminate BIM software management ideas through lectures, articles, courses, and research projects.[22] Researchers in economics study BIM's potential to optimize the design and construction industry as a whole, identifying and quantifying legal, financial, and cultural obstacles to the system's wide adoption, or to establish reliable metrics to assess its benefits.[23] At the same time, a growing body of academic and managerial literature promotes BIM through best practices and success stories.[24]

So, as suggested, the growing consensus among industry, academia and government sectors about the urgency of BIM's deployment is itself another manifestation of the infrastructural scale of the project—and of its universalist ambition. No longer phrased as a trading zone but rather as an all-encompassing infrastructural space shaping a wide range of communicative and work practices, the structured images of building simulations, and the managerial ideologies they inscribe, constitute an increasingly hegemonic view of how buildings and other artifacts are designed and built.

I would like to turn now to a series of localized accounts from the field, which offer a glimpse into the ongoing construction of the BIM infrastructure in practice. Snapshots from a larger ethnographic work, they illustrate how the notions of centrality, universality, and seamlessness that populate conventional BIM discourses can be contested in practice (Cardoso Llach 2015b). Revealing seams, uneven distributions, and messy encounters, these localized accounts of two real

[21] For reports on the adoption of BIM in Europe, see Harvey M. Bernstein (2010), and Pete Baxter (2013). For reports on the adoption of BIM in Asia, see Lachmi Khemlani (2012).

[22] For salient examples see Charles M. Eastman (2008), Andrew Witt (2011), and Andrew Witt, Tobias Nolte and Dennis Shelden (2011).

[23] Respectively, Rob Howard and Bo-Christer Björk (2008) and Kristen Barlish and Kenneth Sullivan (2012).

[24] See, for instance Randy Deutsch (2011). For useful case studies, see Carlos Andres Cardenas (2008), Shiro Matsushima (2003). Recent work by Carrie Struts Dossick and Gina Neff (2011) offers a new perspective by collecting and analyzing a wide sample of qualitative data from BIM users in the US and Europe. These researchers usefully illustrate that while the claim of enhancing interoperability costs is true to some extent, messier forms of communication crucial to design coordination (for instance, informal speech) are not enhanced by BIM practices.

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BIM-coordinated projects seek to bring into focus the blurry contours of the BIM project, and the considerable efforts we invest in building it into the dominant infrastructure for architectural production.[25]

2.5 Image One—Confronting a New Physical, Social, and Cognitive Distance

The world runs on paper —Jack Glymph (Pollack 2006)

While BIM processes are premised on the idea of creating a simpler way of managing conflicts during both building design and construction, some actors find it unnecessarily complicated and prone to generate further conflicts. For these skeptics, BIM processes—premised on new technologies as well as on new actors to manage these technologies—are obstructive to traditional forms of design coordination.

Jacques, an engineer working as a project manager in the construction of a large shopping mall in a Middle Eastern city, struggled to come to terms with what he perceived as a new, digitized bureaucracy of design coordination. His skeptical stance towards the new process is summed up with his opinion that "new software and new technologies create[d] new ways for possible misunderstandings" (Interview, May 16, 2011). Used to a process of project coordination based on 2-D drawings printed on paper, where people "sit in a room with the decision makers, each with their own set of drawings, and together discuss and figure out solutions for the issues" he has now to engage, under BIM, with a new technology and a new process based on digital 3-D models. Rather than identifying issues and marking them on paper drawings, Jacques has to confront a new practice of coordination where meeting participants gather around and coordinate their practices around a digital model.

However, in the Mall project, cultural factors and contractual hierarchies challenge the centrality of the simulation and the authority of those who advocate for it, creating tension (compare where the simulation is located in Figs. 2.2 and 2.3). Not without a sense of irony, Jacques describes the 3-D images produced by BIM specialists as "nice" and "impressive," only to remark that they are useless in the construction site—where only 2-D drawings are in fact used. Since the workers on site relied exclusively on 2-D drawings, any inconsistencies between the 3-D model and the 2-D drawings made coordination difficult and threatened impending construction deadlines. To be effective, decisions taken by design coordinators on the 3-D

[25] The actors and events I describe exist within the larger contexts of the desert city and Emirate of Abu Dhabi, the United Arab Emirates, and the Middle East. Far from the relative technological comfort zones of Angloamerica and Western Europe—where BIM processes and technologies are closer to what Paul Edwards terms a "naturalized background."

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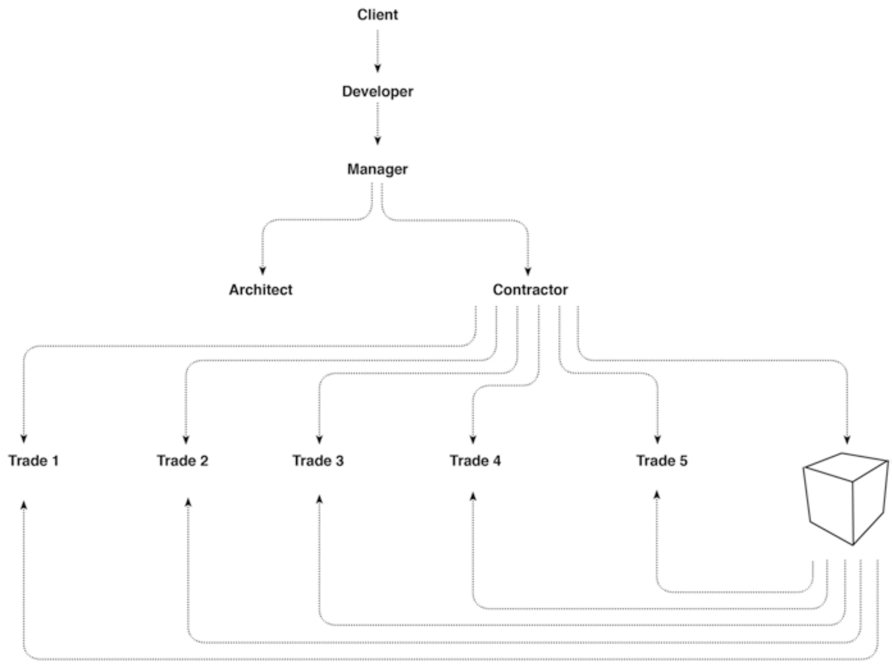

Fig. 2.3 Contractually established hierarchies in the building industry can challenge the centrality simulations as inscribed in conventional representations of BIM (Image by author)

model had to be acted upon by the responsible organization, members of which should promptly produce a new set of 2-D drawings (Fig. 2.6a). This posed a problem for the construction teams, as several of the project's subcontractors were not proficient users of 3-D modeling software, and thus preferred to rely on traditional coordination methods based on 2-D drawings. Consequently, in some cases, conflicts identified in the 3-D model and discussed in meetings had already been solved—or simply did not exist—on 2-D drawings. As a result, some actors on site came to see BIM as a redundant process and a complication. Without the contractual obligation to use BIM, Jacques admits, the builders "would have trashed it at the beginning of the project" (ibid).

Following Mumford's notion of technologies as enablers of different forms of distance, separation, and dissociation, we may see Jacques' skepticism towards BIM as a defense against what he perceives as an estrangement from the project. This estrangement has cognitive, physical, and organizational dimensions. Crucially, new software and hardware systems capable of managing increasingly detailed descriptions have created the need for new specialized practitioners whose skill set spans information management, computational geometry, and architectural engineering skills. So, separated physically from the project's information by a software interface he does not know how to control, and by a new expert acting as gatekeeper, Jacques feels that control has been taken, literally, out of his hands. In his

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skeptical view, the new bureaucracy of project coordination relies on obscure interfaces, intricate channels of verification and approval, and on a new, unwelcome middleman. This bureaucracy of project coordination establishes how information circulates within a project, for example prescribing how design coordinators are to communicate information about design problems to other members of the organization. Distinct actors enact different roles such as inspection, verification, and modeling, and shepherd conflict information from conflict detection to, ideally, resolution (Fig. 2.4).

Furthermore, Jacques thinks that the focus on the simulation changes the dynamics of coordination meetings, taking away from less structured verbal interactions around physical drawings:

> "In the days before BIM, when there was an important clash people would sit together, would call each other, set a meeting, sit together, have a good fight, either the MEP would lower his duct or the architect would lower his ceiling, but after the meeting, after the fight, there would be a solution, so…"

The new dynamics of coordination with BIM baffles Jacques, who sees it as a deterrent to what he construes as more the informal and direct verbal exchanges distinctive of traditional coordination. In his view, the distance introduced by the new technical expert, the BIM specialist or coordinator, induces passivity among participants and creates opportunities for misunderstanding:

> "[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…"

Jacques' reluctance to BIM illustrates a familiar irritation towards new technological propositions. He saw computer simulations purporting to channel design and construction coordination as foreign territories where key actors are no longer in touch with the project's information. Alienating key actors who do not have the skills to read, create, or manipulate digital models, the new technical expert was perceived as an obstructive gatekeeper and middleman. As a result, Jacques and those who shared his skepticism refused to see BIM as a legitimate infrastructure for coordination, and reverted back to habitual methods of trust-building and work. Their frustration and resistance could easily be dismissed as a generational or technophobic quirk. However, it also inscribes pragmatism towards the fast-paced context of construction sites. Here, the infrastructural impulse of BIM is contested by an uneven landscape of technological literacy among the organizations and participants, and by long standing traditions of visual communication, organization and coordination work.

Accordingly, a parallel coordination process took place away from the three-dimensional images produced by BIM specialists in the digital models (Fig. 2.5). This parallel coordination occurred in different spaces, under different schedules, and relied on each organization's habitual forms of 2-D coordination.[26] In light of

[26] In the mall project, this was particularly true of the organization in charge of the Mechanical, Engineering and Plumbing (MEP) systems.

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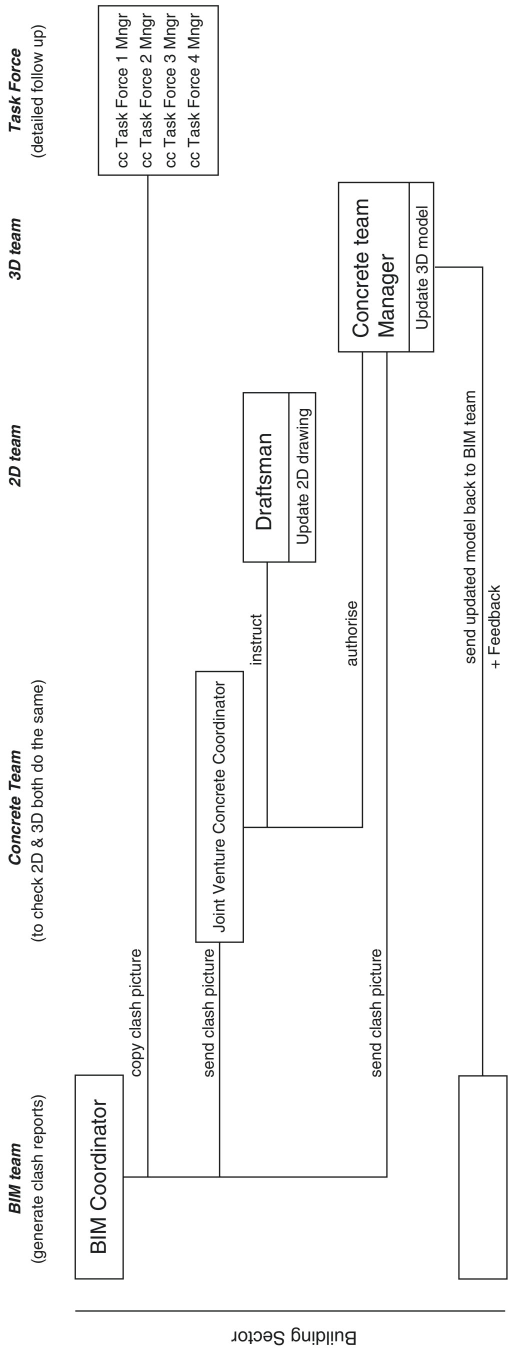

Fig. 2.4 Reconstruction of an actual diagram establishing how information about a design conflict circulates in the organization (Image by author)

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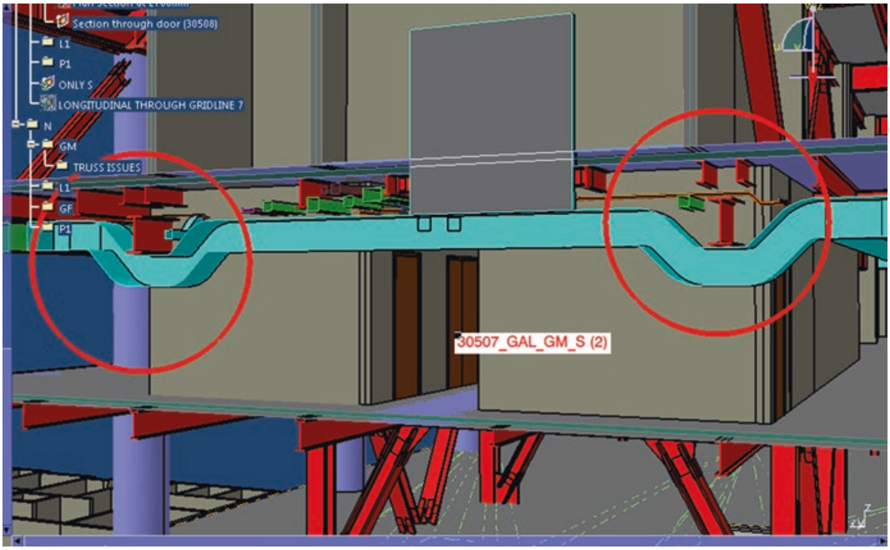

Fig. 2.5 Image of a conflict as reported by a BIM specialist in the mall project (Image by author)

this parallel coordination process, the weekly BIM meetings appeared to many as a legal formalism with dubious benefits on the overall project coordination. At its most entangled, the two coordination processes operated in a sort of denial, failing to acknowledge redundancies between the 2-D and 3-D coordination processes (Fig. 2.6a). Summoned weekly to witness inevitably partial versions of a digital model, trade people, client representatives, BIM consultants and project managers discussed the conflicts represented in the simulation in events I have elsewhere termed "liturgical" because of the participants' standing commitment to BIM rituals despite a lack of evidence to the their effectiveness (Cardoso Llach 2015b: 130).

During the final stages of the construction of the mall, however, after hundreds such meetings had taken place, Jacques articulated a different view of BIM where the computer simulation is not a prescriptive device but a reference tool—a reference for actions already taken on site and a record (instead of a vehicle) of coordination. He admitted that his frustration tempered when he started seeing the BIM as a reference to the team. "…[N]ow that the BIM is *behind us*, BIM has become more popular." No longer seeing the simulation as an instrument purporting to discipline and control, but as a recording tool to account for the actions already performed on site, Jacques started to accept it, and the tensions loosened. The rhetorical relocation of BIM "behind us" is a remarkable move. Jacques puts the computer simulation *in its place* as a supportive device, decentering it and in fact dismantling its purported central and infrastructural role within the project. Compare the coordination processes as diagrammed in Fig. 2.6b, where the model is a verification and a reference with no prescriptive power over the site or construction documents, with the process as diagrammed in Fig. 2.6c, where the model is at the focus of coordination,

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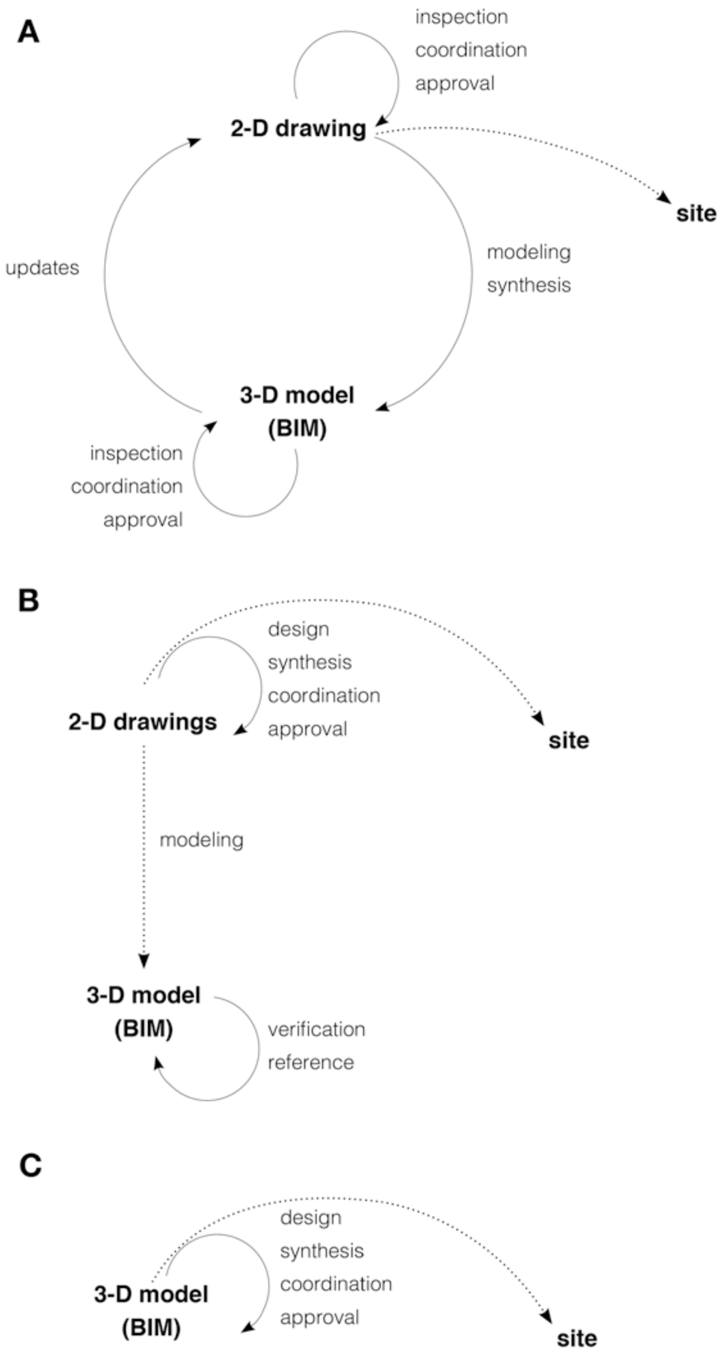

Fig. 2.6 Three different scenarios according to the observed roles of the BIM simulation within the building design and construction coordination at the mall project. (A) shows a redundant cycle of 2-D and 3-D coordination; (B) shows a cycle of 2-D coordination and 3-D verification; (C) shows a cycle where 2-D representations are altogether bypassed (ideal scenario for BIM proponents) (Image by author)

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eliminating 2-D representations entirely. The latter represents the future as imagined by BIM advocates. But Jacques and others are not part of it.

2.6 Image Two—Structured Image as Operative Artifact: Limits to Parametric Flexibility

As we have seen, computer simulations inscribe a desire for managerial efficiency. This is certainly the case with those under the rubric of BIM. However, simulations also reflect on the way architects imagine and manipulate building form.

Aligned with the desire for both data and geometry to imbricate in software, many design practitioners today see architectural models as operative artifacts. As the CAD Project researchers had envisioned, rather than pictures of an object, computational design representations are enlivened artifacts enabling calculations, geometric variation, as well as new kinds knowledge claims. Performing (rather than representing) the design,[27] these structured images occupy a special place in contemporary architectural practices and debates. Within the narrower professional and academic context of architecture, these practices are conventionally known as "parametric design," and are frequently opposed to traditional forms of drafting and modeling—a stance that has prompted equal doses of diatribe and manifesto in architectural studies. If BIM is the use of the structured image to reorganize building design and construction practices around simulations, the loose coalition of design practices grouped under the rubric "parametric design" is the more specific use of such enlivened images by architects to aid in the production of architectural forms.

In contrast with software systems for drafting such as AutoCAD or MicroStation, which equip users with tools that resemble those of a traditional draftsman, parametric modeling software systems are modeled on a metaphor that likens the interface to a builder's or mechanic's table, where materials and tools are available to build *mechanisms* rather than pictorial representations. Accordingly, the users of parametric software systems create the components of their models by defining geometric relationships, mathematical dependencies, and linkages with external data. Rather than fixed artifacts, the resulting models are best understood as networks of dependencies that can be recalculated and recombined to the extent that the model's own internal logic—its structure—allows. It is precisely this structure what enables their geometric plasticity. Systems such as Graphisoft's ArchiCAD, Dassault Systemes' Computer-Aided Three-Dimensional Application (CATIA), Gehry Technologies' Digital Project (DP), Bentley's Generative Components (GC), or McNeel and Associates' Grasshopper are all based on databases where geometric entities can be organized hierarchically, relationally, and in combination with non-geometric attributes. In addition to the drafting and modeling capabilities of its

[27] Or representing *through* performance.

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software predecessors, such systems typically allow users to browse catalogs of geometric operations as well as industry materials and components. Users are thus able to incorporate pre-defined complex objects in their designs (as opposed to designing exclusively with abstract geometric elements such as lines and planes). The affordance to manipulate higher-level entities into a design is often termed in the industry "semantic modeling." Whether defining custom geometrical components or manipulating predefined libraries of architectural entities, it is this process of defining hierarchies and networks of dependency what distinguishes these systems in their users' experiences.

One of the effects of this way of structuring model data is that there is a logical and functional distinction between two kinds of elements: a set of geometric entities or mathematical values at the top of the model's hierarchy controls a subsidiary set of elements whose behavior is dependent on the state of the governing geometry and parameters.

Thus, we can usefully consider two different kinds of encounters with geometry offered by the interfaces of modeling software systems. On the one hand, drafting software systems such as AutoCAD and MicroStation can be seen to enact an *Euclidian* design world inhabited by lines, points, and platonic solids, on which users can operate through replication, symmetry, scaling, and other kinds of linear transformations. In *Euclidian* design worlds, the metaphor of interaction is a drafting table. On the other hand, BIM and parametric software such as Digital Project and Revit can be seen to enact a *Newtonian* design world inhabited by objects, forces, pre-defined components, and materials with attributes on which users can operate through the modeling of forces, the establishment of constraints and of mathematical relationships. In *Newtonian* design worlds, as we saw, the metaphor of interaction is not a drafting table but an engineer's workbench, or a builders' yard—inscribing the CAD notion of design descriptions as structured, operative artifacts, and of software as a space capable of topologically resembling realities outside the computer—a space of simulations. These models' constraints define a design-space: a space of possible variations that a user explores in the process of changing the model by manipulating its governing geometries and parameters, modifying its constraints, or creating new ones. Unlike hand drawings, parametric models can be seen as devices to be operated. For example, Fig. 2.7 illustrates how parametric modeling systems expose the numerical structure of geometric elements in order to enable users to govern designs mathematically. Models built this way can be operated to yield different geometric configurations.[28]

Accordingly, parametric modeling has become a catchphrase for architects who want to stake a claim on the future of architecture.[29] Many designers have embraced

[28] In 2007 I was working for a large corporate firm in the role of "a computational design specialist" and experienced this crisp organizational separation, between the designers and *us*. A specialist – like me and the small team of people in this role- would engage several projects at the same time, providing parametric models and scripts to design teams, who would then "use" them.

[29] Peter Eisenman used the expression in a Spring 2007 lecture at the Massachusetts Institute of Technology. In his keynote speech in SIGRADI in November 2006, John Frazer also described parametric modeling packages (specifically CATIA) as "the single most advanced piece of design software in the market today." More recently, Patrik Schumacher has advanced the notion of "parametricism" as the key to a "new paradigm" for architecture (2012).

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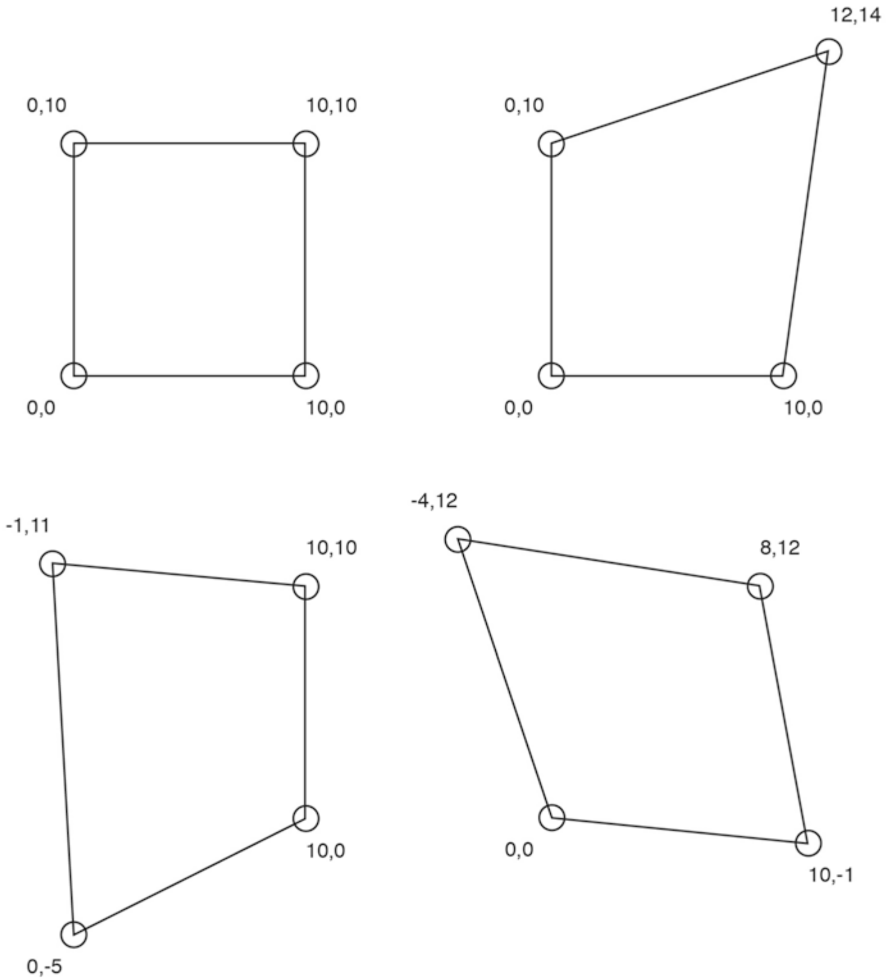

Fig. 2.7 Diagram of a parametric modeling system (Diagram by author after Carlos Barrios Hernandez, Design Procedures : A Computational Framework for Parametric Design and Complex Shapes in Architecture, Thesis, Massachusetts Institute of Technology 2006, p. 41. Accessed August 5, 2015, http://dspace.mit.edu/handle/1721.1/35507)

these practices and tools and the discourses that support them, and they are enthusiastic about the new kinds of geometric plasticity they afford and the air of scientific validity they provide. Prompting design processes based on the modeling of geometric and mathematical constraints (Kilian 2006), and on the managerial efficiencies linked to the implementation of BIM processes (Witt et al. 2011), parametric software systems inscribe the dual promise of aesthetic liberation and managerial control—reflecting architecture's split disciplinary identity as both an artistic and a business practice.

On the field, however, parametric models co-exist with other forms of project development and documentation, such as 2-D CAD drawings and hand sketches, verbal communication, and with cultural and legal boundaries that can challenge the legitimacy of parametric software systems as vehicles of design. As teams of BIM consultants develop parametric models to address budget and scheduling constraints on the field, they confront a tradeoff between precision and flexibility inherent to structured computational representations. Seeking to harness the model's flexibility to affect changes to the design of a building, they struggle to establish the legitimacy of the parametric model—and of their authority as designers—against other groups with their own techniques of representation and cultures of work.

Our site is the headquarters office of a large organization planning a municipal museum and gallery complex in Abu Dhabi, UAE.[30] A large joint effort by builders of different professions and trades—engineers, architects, planners, and subcontractors—the organization's focus is to interpret the building's architectural design and develop estimates, plan logistics as well as make changes to the design to fit structural and budgetary concerns. At this tender stage, the builders compete with other building organizations for the construction contract, and thus producing a feasible plan to deliver the building within strict scheduling and budget constraints is crucial. In this context, computer simulations are expected to provide reliable data about the project, as well as a tool for adjusting the architectural design to best fit within budget and schedule—a process termed "value engineering."

The building's design establishes four exhibition wings converging into a large central hall sustained by a set of steel girders spanning one hundred meters across a very large urban site. The architects obtained the building's unconventional shape parametrically, by using clever mathematical techniques to control geometric variation across the large metallic structure. In the architectural renderings and 2-D drawings made available to the builders, the building appears as a smooth shape undulating elegantly and merging with its context. The team of BIM consultants was able to produce the model by developing a simple parametric component: a structured computational description of a generic arc capable of generating multiple geometric conditions as required by the design's mathematical rules.[31] This component was an arc-shaped parametric component capable of adopting different shapes in response to a parameter indexing the position of each particular arc instance in the project, and to a geometric set of three insertion points. The component responded to the parameters adapting the position of each one of the control points defining the arc. This behavior was guided by a polynomial equation embedded in the parametric component. The equation, part of the architectural documents for the project, became a line of computer code in the parametric component developed by the BIM specialists (Fig. 2.8).

Manually modeling each of the building's wings, each comprising several dozens of such arcs, would have been time consuming, so the team decided to implement a computer program to automatically generate and deploy the design's components onto the 3-D space of the simulation. The resulting geometry was then used as scaffolding for other, subsidiary elements such as the geometric panels representing the

[30] Some details about the project have been changed, and the names have been omitted, to protect the anonymity of the subjects.

[31] As an embedded participant observer during this research, the author was directly involved in the activities described here.

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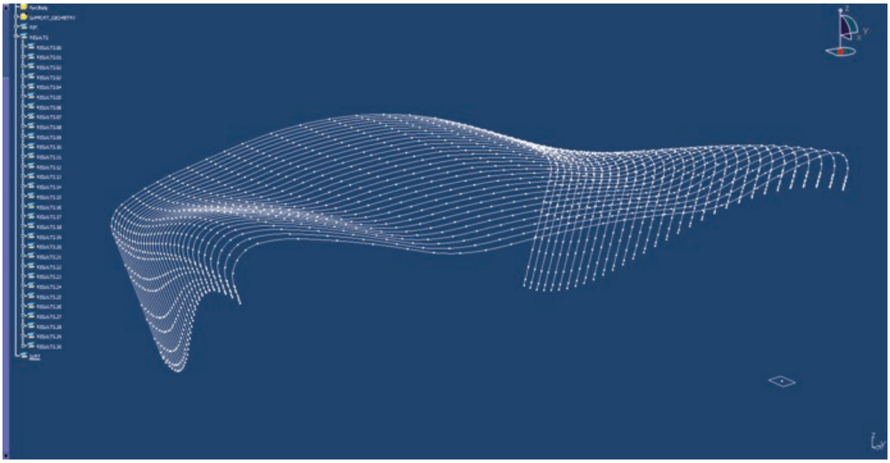

Fig. 2.8 A model developed with a parametric component called "Power Copy" in Digital Project, as it semi-automatically generates arc variations for the Gallery (Image by author)

cladding of the façade, and the steel structure underlying the building's skin.[32] Thus, a remarkably simple parametric element (the file was under 50 Kb) was the fundamental module for building a seemingly complex geometric model. Despite the light file size, this component was "logic-heavy": it encoded mathematical rules generative of the myriad geometric conditions required to describe the building. The image in Fig. 2.9 shows how by changing values in the polynomial equation the overall shape of a building, or building component, can be affected.

Encoded in the structured description of a parametric component, the logic of the design afforded the model certain flexibility. By changing the parameters driving the model—the variables in the polynomial equation—the software could recalculate the model in its entirety, producing different formal arrangements that could be queried for geometric properties, dimensions, and material quantities. This seemed to give the BIM team the ability to improve their quantity estimates, budgets, service paths, and to identify potential logistic problems. From the BIM specialists' perspective, the model's flexibility would also enable the organization to precisely describe (and thus build) different versions of the building's design while respecting its architectural logic and intent. And yet, these possibilities were not always understood nor well received within the organization. On the one hand, the model's flexibility was constrained geometrically to transformations of the building's shape that accorded with the model's overall logic, thus restricting the team's ability to produce (and imagine) alternatives departing too far from the project's basic intent. On the other, the BIM specialists' attempts to affect design decisions were perceived by some actors as an infringement of professional

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

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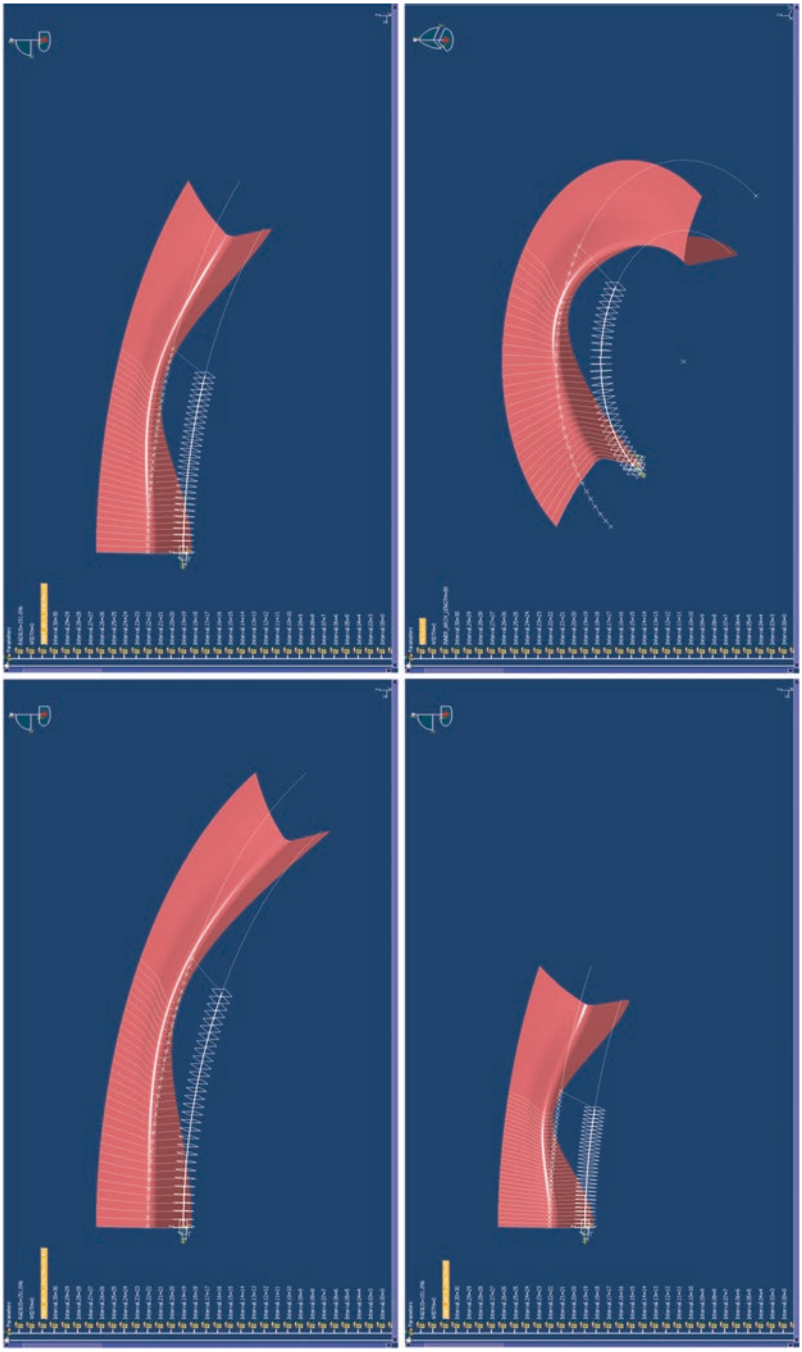

Fig. 2.9 In a parametric model, by changing values in a polynomial equation, the overall shape of a building, or building component, can be affected (Image by author)

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boundaries. Used to thinking of computers as technical supports, these actors felt the need to keep the BIM team "in its place": not at the center but in the periphery of the design.

Despite the BIM team leader's best efforts to colonize this center—to stake a claim on design for the simulation and for his team—the cultural and contractual separation between design and construction prevailed. As Gabriela Goldschmidt's contribution to this volume explains, hand sketches and collages are inherently open-ended and open to interpretation, and thus have advantages as vehicles of design discussions. But these media also inscribe the demarcation of professional territories. Despite the parametric flexibility of the model, the computer simulation was kept "in its place" as a tool for building representation and quantification, *outside* the space of design—not so much an infrastructural system, but one of many in a network of social, technical, and material actors.

2.7 Conclusion

In "Infrastructure and Modernity," Paul Edwards discusses how in the Western world many physical infrastructures—such as electric and water grids—are part of a "naturalized background" that only becomes visible in the event of its failure. Taken for granted, these large socio-technical systems become enmeshed with the fabric of modern life. To be modern, he proposes, is "to live within and by means of infrastructures," a condition that, he argues, poses challenges concerning the different scales at which historical and epistemological analyses may be realized (Edwards 2004: 188).[33] In some contexts, particularly within the Anglo-American and Western European worlds, the governmental and industrial push towards standardization has brought BIM practices and technologies closer to being part of the "naturalized background" of architectural practice. Receding into the background, the systems and discourses placing computer simulations at the center of design and construction have come to shape the expectations and desires of entire professional groups, prompting a new imaginary of building design. This imaginary was fundamentally enabled by the postwar emergence of what I have termed here the "structured image," and the cultures of interdisciplinary collaborative work that it made possible.

From these skeletal origins to the contemporary globalist project to reorganize a vastly diverse landscape of design and building practices, software simulations no longer configure tools or aids for design, but rather hybrid human-machine infrastructures increasingly mediating the production of the built environment. Inscribing protocols of information production, manipulation, and exchange across disciplines, simulations are not merely trading zones enabling a cross-disciplinary collaboration, but rather vast infrastructural spaces enabling transnational geographies of practice.

[33] For a discussion on ethnographic studies of infrastructure see Susan Leigh Star (1999), for a discussion of the human aspects of cyberinfrastructures, see (Lee et al. 2006).

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Comprising software, management, and rhetoric, this project is unique in its ambition to organize a plurality of design and building practices across disciplinary and geographical boundaries. Fundamentally enabled by the postwar discovery of a new kind of structured image animated by computing technologies for data storage, manipulation, and exchange, BIM is a disclosure of what Castells has suggestively termed the "network society" (Castells 2009).

Examining BIM as a historically situated and messy socio-technical infrastructure *project*, I want to call attention to the ongoing efforts our society invests on its deployment and maintenance. Making these vast networks of socio-technical work visible should concern us as citizens and as academics, and their unpacking demands an expanded set of analytical tools and a new approach to method.

As we saw, through both digital and legal standards, this project encompasses (and is necessarily premised on) the homogenization of a diverse ecology of design and construction practices. Enacting an imperialist impulse to colonize and reorganize worlds of practice, BIM discourses emphasize the centrality of simulations and the universality of the socio-technical protocols for its production. However, as this chapter shows, for simulations to enact this centrality, a plurality of actors need to commit to visual, organizational, and technical epistemologies whose adoption is neither trivial nor universal. The two accounts above contribute a view of how this impulse can encounter creative forms of resistance, revealing the imagery of BIM simulations as territories where the kind of modernity simulations inscribed is not only advanced but also contested, reinterpreted, and reappropriated.

The practices of redundancy, reconstruction, and redescription that BIM discourses seek to eliminate may tell us something fundamental about contemporary ecologies of design production and coordination. By casting these practices as targets of managerial optimization, the dominant BIM narrative misses a key dynamic of evolving traditions of practice: that no technology simply replaces a prior one but rather coexists, in a contingent and a negotiated fashion, with existing instruments and practices in a new socio-technical and material assemblage. The appropriations and re-readings of BIM, such as Jacques' reuse of the model as a reference tool (placing BIM "behind us"), speak of alternative versions of modernity where the radical centrality proposed by technology advocates is challenged and replaced by what we may call "porous and generative peripheries" (Cardoso Llach 2015b).

Fundamentally obscured by techno-discourse—so prone to prophecy and mystification—these contingencies need to come into focus as subjects of analysis in studies of design, technology, and society. Treading through both historical and ethnographic evidence, this chapter has aimed at illustrating how such a task may be undertaken.

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