
Tracing Design Ecologies

Collecting and Visualizing Ephemeral Data as a Method in Design and Technology Studies

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What does the phenomenon of design look like from the perspective of data? This chapter explores ways to make visible the sociodigital infrastructures of contemporary design practices. Drawing on images of agency as relational and distributed, it proposes “design ecologies” as an analytical category to reflect on such practices, and explores it through a case study describing the collaborative coordination of a large architectural project.¹ The chapter discusses in detail my work to study this project as a participant observer defining and collecting digital traces of thousands of design conflicts reported during its coordination, and developing a series of interpretive visualizations of these data. These visualizations—a tree, a map, a field, and a network—elicit distinct images of the design process and appear as illustrations of a design-ecological condition, as elements of an inchoate visual discourse about design ecologies, and finally as constituents of this chapter’s underlying argument: that the ephemeral data produced during design, and the images of practice they inscribe, configure important sites of inquiry in studies of design and technology—sites we may explore in order to trace new analytic, speculative, or critical cartographies of sociotechnical design practices.

The chapter is organized as follows. The second section describes the work of a team of computer-savvy architects as they collaborate in the process of coordinating the design of a large architectural project, chiefly by assembling a highly detailed computer simulation of the building. Different from a conventional CAD model, this simulation combines the contributions of multiple organizations. This is an increasingly dominant mode of design production—known in the building industry as building information modeling (BIM)—premised on the centrality of computer simulations to both design and construction. Tracing the figure of the design coordinator and of the digital artifacts they collaboratively assemble and manipulate, the chapter offers insight into the social, technical, and material practices of BIM.

The third section traces coordinators’ negotiations leading to the definition of a common data representation for design conflicts, and shows how their circulation

is essential to this type of design production. Of interest here is the contingent production of design conflict data. While dominant narratives about computerized design methods emphasize seamless collaboration, interoperability, and efficiency, the structure of design coordination data in this project resulted from multiple negotiations involving, for example, technical concerns, design sensibilities, professional hierarchies, habits of record keeping, and personal idiosyncrasies of which the data are themselves vestiges. A close examination of one such design conflict reveals it as a situated digital artifact comprising multiple media, heterogeneous and redundant fields, and visual conventions variously linked to the coordination activities taking place “outside” the simulation. I further discuss the collaborative definition for a common data structure for design conflicts and their collection as codependent processes, and reflect on my own positioning as a researcher with active roles as both an observer and active participant on this site. For example, the formalizing of a common definition of design conflict data for collection purposes is discussed as a type of research intervention that in fact challenges the very ephemerality of the data being collected.

After a brief discussion confronting the epistemic legacies of data visualization practices in surveillance and management, the fifth section presents four different data visualizations of a dataset of design conflicts. I introduce these as illustrations of a design-ecological condition and show how their different visual structures—a tree, a map, a field, and a network—elicit different types of analyses and invoke different conceptualizations of the design process they inscribe. The chapter concludes by reflecting on the notions and methods presented, proposing that tracing design ecologies might help us expand the reach of our ethnographic and historical accounts of design. It shows that by incorporating data critically as an ethnographic material susceptible of visual and computational analysis, along other types of observation and reflection, design-ecological studies can help us make visible the sociodigital infrastructures that condition the phenomenon of contemporary design, and challenge conventional narratives about individual authorial agency in design.

A brief note on method: During the period of participant observation that originated this project I had a dual role as a researcher and as a member of the design coordination team of a large architectural project. This gave me unparalleled access to the culture of design coordination I describe, and to its digital artifacts. However, the visualizations and analyses I present in this chapter were produced after this period of fieldwork for the purposes of this study, and did not support the project or any of the organizations involved. In other words, they were instruments of ethnographic inquiry in a study of design coordination and not instruments of management or coordination.²

Buildings and Data

Moving away from 2-D drawings, recent industry practices in architecture and engineering design overwhelmingly favor 3-D digital models as the main vehicles of design coordination. This trend, which encompasses both software systems and managerial practices, is known in the architectural and engineering worlds as building information modeling (BIM). At its core, BIM is about using software to develop a highly detailed 3-D model of the building before it is built. Assembled from the contributions of different organizations involved in the building’s design

(architects and engineers as well as consultants and subcontractors), these models purport to describe not only the building's shape, but also other relevant information such as the building's materials, budget, structural performance, financial viability, logistics, and more. Assembling the information from all these actors into a single, conflict-free digital model is the central challenge of design coordination. It is a reasonable proposition. In most cases, assembling a building digitally can be orders of magnitude cheaper than building it, so potential design conflicts can be addressed before they make it to the construction site. Thus, BIM is less about representation than about organization, less about the aesthetics of design than about its production and management—and its execution. Reflecting a growing consensus among architects, engineers, software companies, and governments, BIM is frequently described as a transformative technology able to collapse the boundary between design and construction and to redefine the technical, legal, and cultural frameworks of the entire building industry.³ Accordingly—and updating a Cold War era technological imaginary of design⁴—widely circulating success stories tout BIM software and its associated process as purveyors of increased creative freedom to designers and, ambivalently, as means to maximize managerial efficiency through improved accounting and communication.

The efficiencies of BIM are often put in contrast with earlier traditions of design coordination based on 2-D drawings. In these traditions, which remain the norm in many design and building practices, teams of engineers, architects, consultants, and tradespeople gather around large tables armed with color markers, and discuss the proper course of action to solve design conflicts such as a clash between a ventilation duct and a concrete beam, a poorly calculated staircase, or a steel column disrupting a path of circulation. BIM shifts the site of coordination from paper to the screen.⁵ In BIM, data produced by all trades are collected, translated, aggregated, inspected, and negotiated into a single digital model, and this endows the digital model, and those who make it, with a new kind authority (figure 1).

And yet, despite BIM's promises of seamless transits between design and construction, putting a building together remains, and will remain for the foreseeable future, a stubborn and cumbersome endeavor. It requires the alignment of numerous factors that exceed the scope of digital representations and transactions such as people—clients, engineers, designers, workers, consultants—and their professional jargons, habits of representation, and technological preferences—not to mention the proverbially obstinate stones, bricks, and glass that actually form it. Similarly, despite the familiar rhetoric of efficiency and seamlessness, building data do not come together seamlessly or by themselves. They are laboriously put together by a collective of people, organizations, and software—composing what McCann and colleagues have called, in the context of planning, “assemblage work” (2013). A protagonist of this new coordination process is the “BIM coordinator,” whose role is to iteratively collect, translate, aggregate, analyze, and report on building data. Because of their important role in design coordination, these coordinators deserve further analysis.

In our site, for example, the work of BIM coordinators was organized cyclically roughly along the following sequence. First, BIM coordinators *collected* data in the form of digital models from each trade organization. Second, in order to incorporate these into the central model, they *translated* the models. As different organizations employed different software systems and modeling standards, this was often a daunting task. The diversity reflected not only different habits of representation

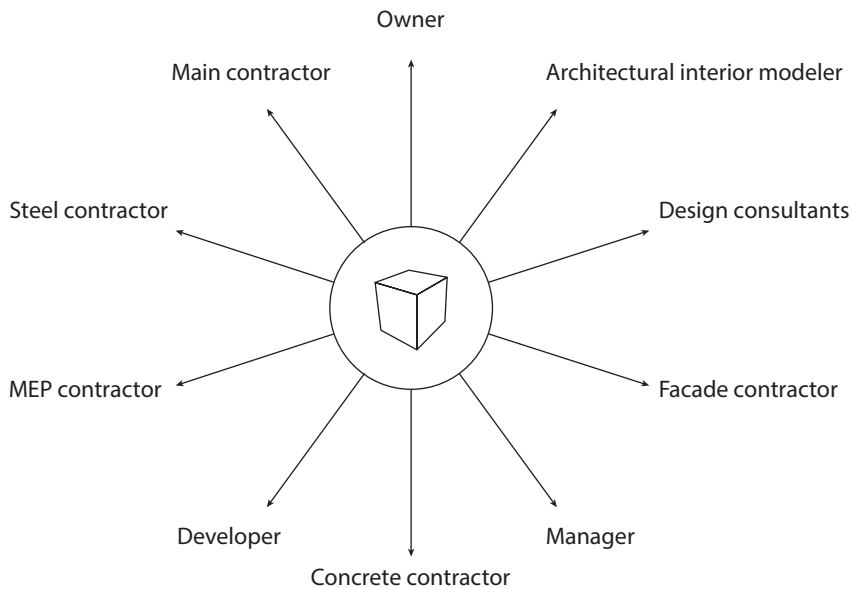


FIGURE 1: Contrasting with traditional representations emphasizing vertical contractual and legal hierarchies in design, diagrammatic representations of BIM typically show the digital model at the center of all design and building trades.

and work, but also technical literacies. For example, the concrete subcontractor and the architects used Autodesk Revit (increasingly an industry standard); the steel subcontractor used the specialized package Tekla; the mechanical systems subcontractor used AutoCAD 3-D; and so on. Grappling with this diverse landscape of software, BIM coordinators spent a significant amount of energy struggling to establish—and then enforcing—protocols of information production and exchange such as file formats, geolocation information, and modeling standards.⁶

In the project, contracts specified that all models had to be exported in IFC format, an open (nonproprietary) file format used as a BIM standard.⁷ Because BIM relies on the unification of protocols for model production and exchange as a way to reduce “interoperability costs,”⁸ it can be fundamentally seen as a standardization project—and a disciplining one. This rhetoric hides the often laborious and time-intensive work of translation performed by coordinators.

Third, coordinators *aggregated*. One of BIM’s promises is to reduce redundancies in the design and construction process by centralizing data from different sources into a model and software platform.⁹ Thus, by stitching each new update with the larger digital model, coordinators progressively composed what amounted to an aggregate model of the building from the contributions of the different organizations. Fourth, coordinators *inspected* the aggregate model for design conflicts, often with the aid of automated “clash-detection” algorithms. These algorithms, first introduced in the early CAD systems developed in the 1970s, yield exhaustive lists of clashes between sets of geometric elements. These clashes indicate discrepancies between the digital models of the different building systems, but they can be misleading. Oftentimes a modeling feature of no consequence or a slight error in the placement of the model produced hundreds of conflicts that did not in fact pose a threat to the project. Thus, when inspecting the BIM for actual conflicts, experienced coordinators relied not only on the software’s clash-detecting algo-

rithms but also on their knowledge of construction and their understanding of the modeling idiosyncrasies of the contributing organizations. Last, coordinators *reported* the conflicts resulting from these inspections to representatives of the organizations involved, who then convened in a coordination meeting to review, discuss, and determine a responsible party for each of the reported conflicts. On a typical meeting coordinators used the BIM modeling software to present each conflict to participants, who debated—sometimes heatedly—until a responsible party was identified, a plan was agreed upon, and a record was created by the coordinator, usually on an Excel spreadsheet. Actions often involved a design change—for example moving a door, changing a staircase, relocating a duct. These changes had then to be made effective by revising both the BIM and, more urgently, the 2-D drawings used to organize the construction work on site.

Throughout the process, resilient traditions of work, professional idiosyncrasies, and at times blunt skepticism toward the new process could (and often did) contest the centrality of the digital model and the authority of those commanding it. Our understanding of this context of design coordination—this “design ecology”—is what the following sections seek to enrich through the definition, collection, and visualization of data about design conflicts. What can data constructed from BIM coordinators’ ephemeral, disheveled spreadsheets, screenshots, and email attachments relentlessly circulating across these sites reveal about the phenomenon of design?

On Ephemeral Data

Rather than curated to constitute a historical and navigable collection, the ephemeral data explored in this study are vestiges of sociodigital transactions that are typically hidden from view and discarded from the end result. These data are ephemeral as their chief purpose is to assist the everyday tasks of design coordination, serving as leverage to catalyze actions on site before being discarded or forgotten. Without established protocols for their archiving, they are also ephemeral in that the thing that they represent, a design conflict, is supposed to go away—to be resolved. The preservation of these data, when enforced, is a matter of contractual obligation rather than exposure or posterity. In contrast to data produced with archival and curatorial intent,¹⁰ design conflict data are disposable: the ultimate aim of coordination is in fact to remove them from view.

And yet they are central to design. They circulated in emails and spreadsheets among the actors involved in the conflict, and their discussion paced daily coordination meetings. Their resolution punctuated the project’s advance and organized the day-to-day tasks of a very large number of people across different organizations. Design conflict data were central to the sociodigital scaffolding of coordination. At the same time, design conflict data were not uniform. They were spatially and socially situated, and often reflected coordinators’ professional sensibilities and personal record-keeping styles.

Design conflict data are not too distant from what recent work in STS, information science, and human-computer interaction has termed “trace data,” which Geiger and Ribes usefully define as “documents and documentary traces in . . . highly technologically-mediated systems” (2011, 1).¹¹ However, because of the contingencies described in the above paragraph—their artisanal definition and ephemeral character—the design coordination data discussed here have a distinct

quality. The relatively handcrafted, non-curated, and ephemeral data produced during messy sociodigital exchanges of design have remained relatively unexplored.¹² In what follows I return to our project to illustrate the specific quality of these data, and to show how they constitute rich sites for inquiry into situated practices of design, how we may develop instruments for their collection, analysis, and interpretation, and what their visual representation may help reveal about contemporary sociodigital design practices.

As coordination advanced at a frantic pace in the project, a small team of coordinators managed the coordination of similarly sized portions of the building, reporting dozens of new design conflicts each week. Each coordinator defined design conflicts intentionally and idiosyncratically—their record-keeping habits did not conform to a single standard and the design conflict metadata (the template establishing the categories of data to be recorded) reflected their different specialties and personal coordination styles.¹³ Despite these differences, all conflicts involved certain essential details, such as the conflict's location in the building, the organizations likely to be involved in their resolution, the name of the person in charge, a description, and a date. In some cases, design conflict data incorporated multiple media, actors, and modes of representation. For example, data about a design conflict could comprise screenshots of the 3-D model, photographs of the construction site, official requests for information (RFI), as well as sketches, drawings, or excerpts of architectural plans. Often design conflicts were more sternly defined—a row in a spreadsheet with a location and a short description. In their heterogeneity design conflict data valuably trace design coordination as a sociodigital practice combining an organization's information management protocols, the affordances of software environments, and coordinators' professional inclinations and styles. As vestiges of the design coordination process, they give us access to social, technical, ideological, organizational, and material aspects of design.

This is nicely illustrated in figure 2, an image describing one of the thousands of conflicts reported during the project's design and collected for this study. The background image, an interior view of the BIM, shows two steel columns clashing with a ceiling. However, no walls are visible. The coordinator "hid" them digitally in order to create an unobstructed view of the structure. Further, the "camera" was placed and oriented to capture enough of the context to situate the conflict within the project. Annotations in red indicate the precise location of the clashes and the key measurements in the scene (the distance from floor to ceiling and the door's height). A 2-D plan of the building, itself augmented by sketches drawn by hand, provides another layer of information—a more conventional representation. Finally, a text window provides the conflict's description, index, and location expressed in grid lines. Combining different 2-D and 3-D media and multiple layers of information—including both digital and analog media—the image of the design conflict is also an illustration of the plurality of media and visual codes at play in design coordination data.

Defining a method for collecting these data for the purposes of this research posed the challenge of creating a somewhat consistent system that made conflicts comparable across coordinators, without getting rid of the data's ephemeral character, or disrupting coordinators' record-keeping habits.¹⁴ Reaching this common definition (the conflict's "metadata") was in fact a research intervention that involved multiple conversations with the team of coordinators over a period of several weeks. Reactions varied from indifference to defensiveness and skepti-

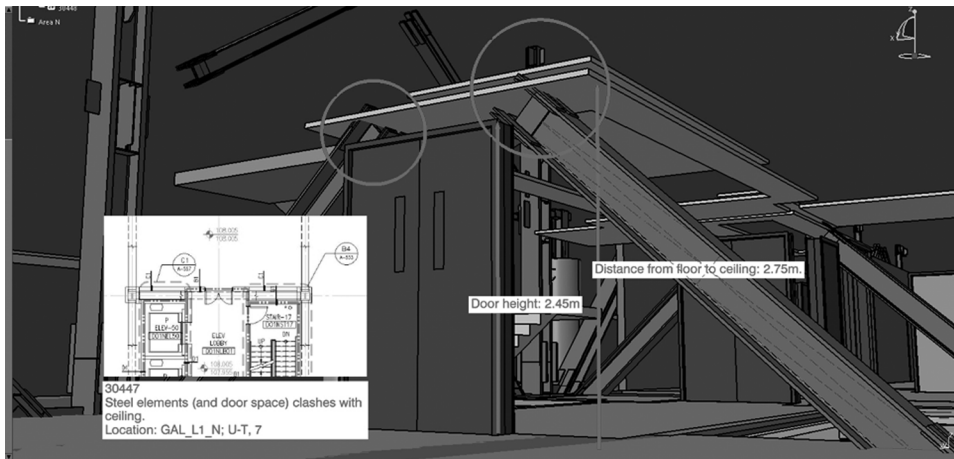


FIGURE 2: One of the thousands of design conflicts documents a clash between structural elements and an architectural ceiling.

cism. Hierarchies mattered. For example, a senior coordinator repeatedly made clear her expectation that the categories they used in their logs were preserved, and that her nomenclature was kept as the main index to the data. The final definition of conflict (C) reflected many such compromises and included the following categories:

$C = \{ \text{index, building, level, trade, int code, discipline, zone, grid-lines, description, opening date, status, action, responsible person, responsible organization, RFI, next meeting date, action as agreed in meeting} \}$

The conflict's metadata inscribe compromises and redundancies, revealing how personal, site-specific, and institutional nomenclatures converged. Redundancies and overlaps in the conflict metadata indicate that methods of spatial demarcation, professional hierarchies, and the disciplinary boundaries separating designers, builders, and other actors fluctuated during the complex process of producing a building. We might see these redundancies as an illustration of how data are always situated and contingent upon particular social, technical, and material contexts.¹⁵ We might think of data about design conflicts as *seamful* rather than seamless.¹⁶

The coexistence of personal and shared nomenclatures in the definition of the design conflict reveals data as compounds of idiosyncratic knowledge, on the one hand, and larger, collective knowledge-spaces, on the other.¹⁷ For example, the presence of two different nomenclature fields (*index* and *int-code*) to index conflicts in the database contradicts elemental good practices of information management, but was key to ease coordinators' fears that the system would force them to change their record-keeping habits. As I realized how important it was to preserve these idiosyncratic nomenclatures, a new *index* category allowed me to aggregate design conflict data from different coordinators into a larger dataset (itself an idiosyncrasy of my research design). Preserving a "key" to their prior records, the *int-code* category enabled a diversity of record-keeping styles within the new dataset. As we can see, data collection instruments shape the data they collect, and accordingly, data collection is always a form of intervention.

If redundant nomenclatures reveal the seams between personal and shared forms of record keeping in the construction of conflict data, the spatial categories locating the design conflict physically within the project reveal seams between different spatial nomenclatures and these data's specificity to the physical structure of the building itself. The categories "level" and "building," for example, were specific to the project—a building complex comprising several structures—and reflected the labeling defined by the building's designers in the construction documents. The categories "zone" and "grid-lines" reflected, by contrast, a method for spatial demarcation defined by the coordinators themselves: a rectangular grid dividing the building site into 40 alphabetically labeled square modules of about 10,000 square feet.

This grid provided an alternate abstraction to navigate the space of the project, and itself constituted a key tenet of the coordination process. While used widely by designers, builders, contractors, and subcontractors throughout the life of the project, the grid was controversial to some actors who perceived it as an unnecessary complication and as a transgression of the coordinators' professional jurisdiction. The coexistence of both spatial methods of demarcation in the design project reveals these data also as places where redundant kinds of spatial notation intersect. This is one reason spatial data are not easily abstracted or transferred—they are, by their very nature, situated.

Finally, the metadata tell us something key about BIM coordination: the collective use of a computer simulation as both an anticipatory and an accounting tool. The metadata combine fields accounting for personal and organizational responsibility with these actors' projected or requested actions. They hint at an intricate, digitally enabled bureaucracy that modulates BIM coordination while revealing design conflicts as this bureaucracy's lifeblood. Actions "as suggested by coordinators," actions as "agreed in meeting," fields for responsible person, trade, and involved organization inscribe the fundamentally contentious nature of the coordination process as well as its fragility, which—as I discuss in detail elsewhere—can engender generative forms of resistance.¹⁸ To be sure, design conflict data were both "ephemeral" and "seamful." They reflected plurality, negotiation, site specificity, and redundancy rather than homogeneity, seamlessness, universality, and efficiency.

Once the negotiations about the conflict definition reached a solution that was acceptable for the group of coordinators, I programmed a simple data-collection widget that worked in conjunction with the Excel spreadsheets coordinators already used (figure 3). The widget offered a simple user interface for recording design conflicts as previously defined by the team and aggregated them into a common spreadsheet. Using this tool, the coordination team recorded thousands of design conflicts over a period of about four months. In what follows I describe the process I used to explore these data visually.

A Note on Data Visualization

In asking "what does design *look like* from the perspective of data?" we must consider the nature of visualizations as artifacts in their own right that, just as the data themselves, carry epistemic legacies and interpretive force. As visual theorist Johanna Drucker reminds us, by virtue of their scientific origins and their usage as instruments of management and surveillance, data and their visualizations

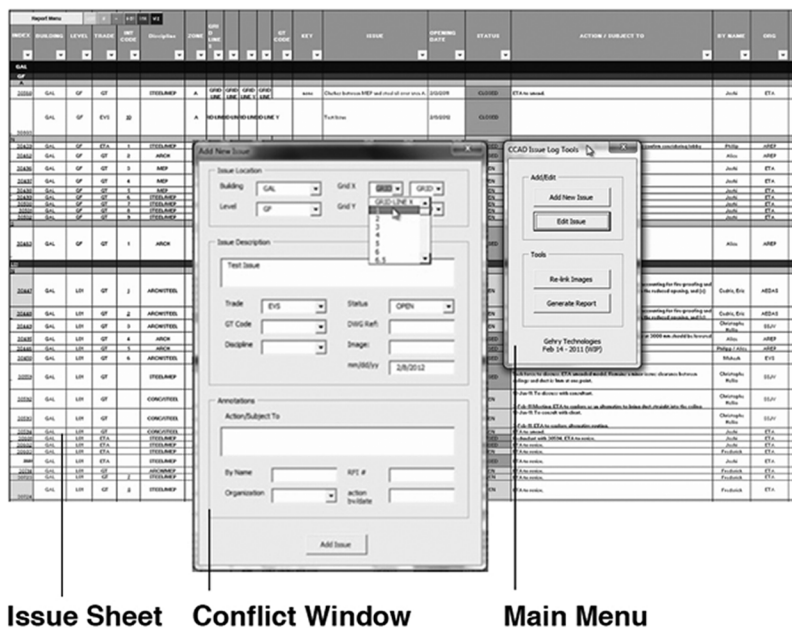


FIGURE 3: Following negotiations about the definition of a conflict, BIM coordinators used this widget to record information about design conflicts during a four-month period of data collection.

often carry with them “assumptions of knowledge as observer independent and certain” (2011). Cautioning against the uncritical use of data visualizations—and developing a critical vocabulary to probe them—Drucker usefully notes that contemporary approaches to data visualization can be traced to long-standing traditions of diagramming, charting, and mapping linked both to the appearance of the printing press and to the 18th-century demands for bureaucratic management of the emerging modern state (2014, 69).¹⁹ Accordingly, contemporary technologies and uses of data visualization are inseparable from governmental impulses to efficiently collect, navigate, and visualize information for purposes of management, surveillance, and militaristic control.²⁰

Contrasting with these approaches, recent work in STS and related fields has sought to consider visual forms of knowledge production as both subjects and vehicles of critical inquiry. They have appropriated, for example, visual and time-based media as instruments to examine sensorial and embodied aspects of technology making and use (Ratto 2011; Lehmann 2012) or film and interactive media not merely as illustrations but as constituents of scholarly arguments (Galison 2015). Scholarly efforts to use data visualizations as interpretive instruments have sought to reconcile long-standing traditions of visual communication (Tufte 2001) with an expanding landscape of computational techniques (Fry 2007; Murray 2013) to explore, for example, data visualization’s capacities as instruments of artistic exploration (Viégas and Wattenberg 2007), media studies (Manovich 2012, 2016), human-machine interaction analysis (Loukissas and Mindell 2012), and humanistic inquiry (Drucker 2011). We may think of the approaches represented in this indicative sample as examples of an interpretive countertradition challenging data visualization’s complicated epistemic legacies in management, surveillance, and militarism.

Extending this countertradition to sociotechnical studies of design, the following section discusses a series of four visualizations of design conflict data. Their purpose is strictly cartographical. The four visualizations—a tree, a map, a field, and a network—all invoke different understandings of the design process. They are examples of an experimental cartography of design production, illustrations of a design-ecological condition in BIM coordination, and, finally, elements of an inchoate visual discourse about design ecologies.

The Graphical Construction of Ephemeral Data

Trees: Tracing Hierarchy and Growth

Figure 4 shows a series of data visualizations where data about design conflicts are organized hierarchically as a tree.²¹ The visualization maps the traces of design conflicts in time along a set of concentric rings representing the building zone and the responsible trade. To create this visualization I wrote a program that parsed all conflicts and represented them as Bezier lines inflected at points that in turn indicate the conflict's location (e.g., building 1, building 2, etc.) and trade (e.g., steel, architecture, etc.). The result is a radial tree where the leaves are conflicts and the branches provide context information about the conflict. Each leaf represents a design conflict, which in turn indexes spatial and temporal coordinates as well as graphics and annotations. However, the visualization places emphasis on two key categories: the conflict's spatial location and its trade in a hierarchical manner, while displaying the other categories in a secondary panel in the graphical user interface.

My goal with this visualization was to give a visual representation to the evolving process of design coordination. Enlivened by the data, it reveals visually the surprisingly stable growth of the tree through the four months of data collection. The visualization makes visible the explosion of conflicts related to mechanical systems (MEP) that started during the eighth week of the data collection period and that came to occupy nearly half of all the coordination efforts toward the end. This explosion reflected observations in the field to the effect that the coordination enterprise seemed at times to be solely focused on managing conflicts in the design of the mechanical systems (Cardoso Llach 2015, 121–34). The radial tree is also useful to reveal the variations in the relative importance of different trades in the coordination efforts, and on the coordination loads assigned to each of the trade organizations. As the tree gets denser, it encodes a history of coordination without losing detail—making it an interactive document indexing and providing access to a significant amount of visual and textual information.

Used for centuries to record genealogical information, trees are one of the oldest forms of information visualization. As knowledge structures, they emphasize relationships such as distance, adjacency, derivation, hierarchy, and consanguinity (Drucker 2014). Trees can grow and branch out and their elements can be rearranged, but their organization is invariably hierarchical and centralized. This is both their expressive capacity and their limitation. Visualizing design as a tree reinforces a hierarchical view of design practice placing an abstract model at the center of a ring of trades. Notably, this type of representation closely resembles the diagrammatic representation of design practice commonly used by advocates of BIM (figure 1). Placing the model at the center, the visualization makes

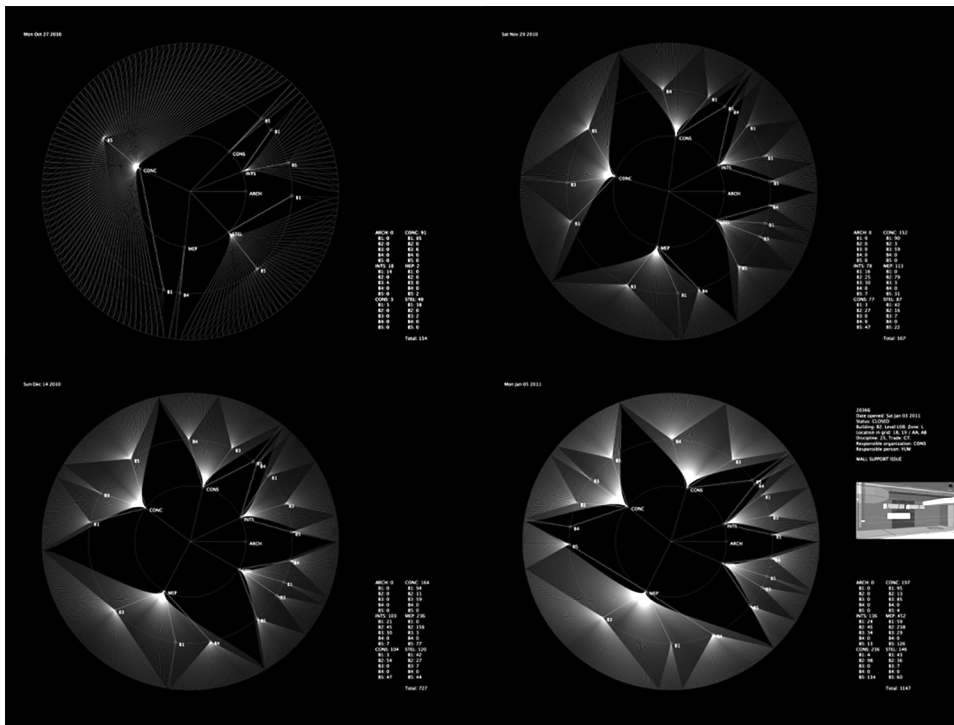


FIGURE 4: The visualization interactively represents the state of design coordination at different stages of the project by tracing the design conflicts recorded by a team of BIM coordinators.

the panoptic aspiration of BIM discourse—“enlivened” by the coordination data, it documents this aspiration in a way that reveals its often hidden and laborious production.

A design-ecological tree traces hierarchy and growth.

Fields: Tracing Clusters of Coordination Activity

In a second visualization, I sought to avoid the hierarchical organization of the data. Instead of a tree, I programmed the visualization as a rectangular grid where issues cluster by trade and building (figure 5). Design conflicts appear here not as branches or leaves but as abstract elements distributed spatially in clusters reflecting location and organization. By interactively changing the date parameter, one can see the variation of distribution of issues in time—a process that resembles (only superficially) a dynamic system where multiple elements would seem to affect each other. Without a center or root, or a reference to the physical world, the visualization evokes a view of design as a field where elements cluster around particular events (trades, indicated by colors) and subspaces (buildings, indicated by the vertical position of each conflict element), not unlike the representation of a meteorological event. The space of the representation is abstract and does not resemble the physical form of the project. It displays coordination activity as clusters of conflicts organized by building and trade, and by a series of numerical parameters in a secondary panel in the visualization’s interface.

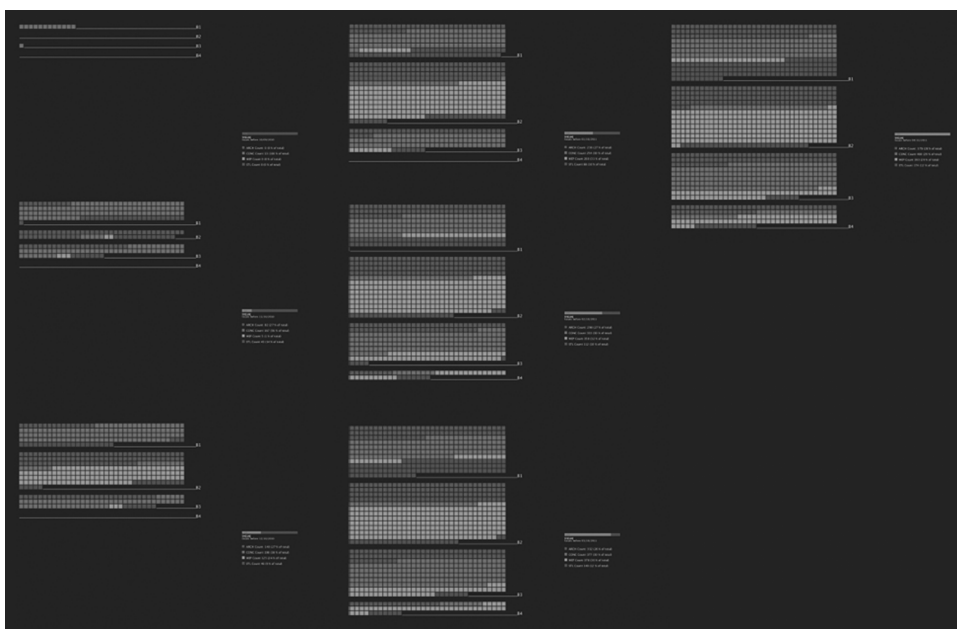


FIGURE 5: Coordination data represented as an abstract field at seven different moments during the period of observation. Different areas of the project are indicated as horizontal sections, and conflicts involving different trades are classified by color.

In order to create a view of design as a changing field, the program ignores location and reconstructs conflict data in an abstract grid. Each section of the grid dynamically displays the state of design coordination in a different area of the building, in time. This abstraction enables comparative analyses across conflicts, organizations, and trades and a bird's-eye view of the state of coordination as expressed by the distributions of conflicts and their types.

A design-ecological field traces clusters of coordination activity.

Maps: Tracing Design Spatially

A third set of visualizations explores the spatial dimension of the conflict data. Rather than a hierarchical representation of the design process as a radial tree, or an abstract one as a field, this visualization relinks the conflict data to the building's physical form and the space it occupies. The visualization takes each conflict's location data and uses them to reconstruct a plan of the building, taking the amount of conflict data as a visual unit. The resolution of the visualization is given by the project's grid of 10 feet by 10 feet, which provides enough detail to discern the building's configuration.

Tracing the spatial dimension of design conflicts in time enables new readings of the design process. The building's shape becomes apparent only to the extent that design conflicts are being reported and addressed, dematerializing the building and rematerializing it as a function of the managerial processes that modulate its production. The visualization thus defines the building literally—and visually—as

a space of conflicts, relocating the managerial processes that go into design production in a virtual representation of the physical space.

What these visualizations reveal is the incidence of issues in a particular area. The intensity of conflicts is represented spatially and in time. These are explored in a number of ways. The visualizations in figures 6 and 7 (top) represent the incidence of conflicts in a particular area of the project geometrically—by scaling a shape. This produces a conflict map useful to understand the general distribution of conflicts and the critical zones in the project. The bottom set represents conflict incidence through color—as a “heatmap”—which improves the legibility of the visualization and represents conflict incidence with greater precision.

A design-ecological map rekindles the political and managerial with the spatial.

Networks: Tracing Relations

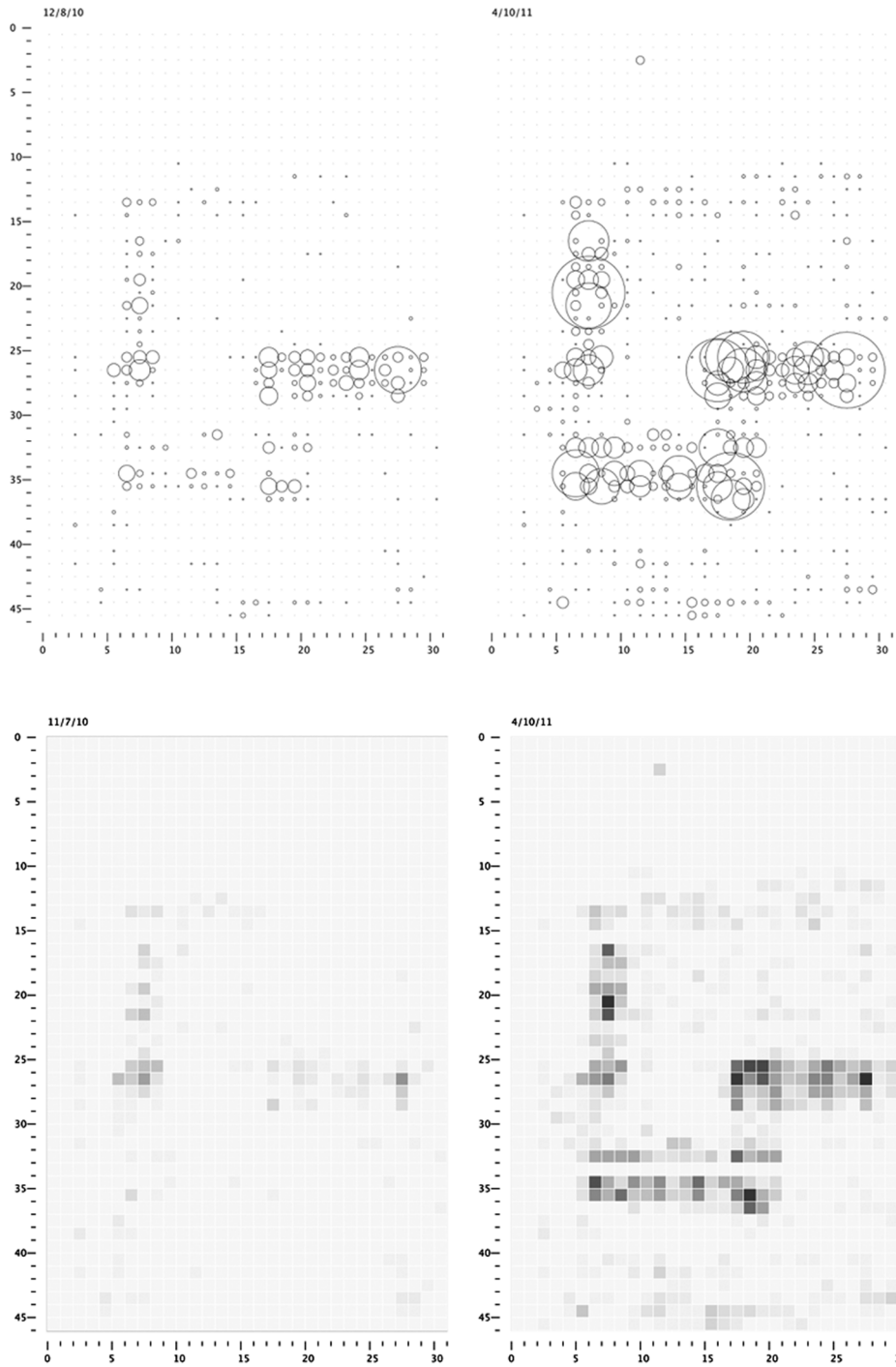
The last set of visualizations uses networks to explore and visualize different types of associations in the conflict data. These visualizations use special clustering algorithms to spatialize the concepts inscribed in the dataset and were developed using ORA-NetScene, a network analysis and visualization software developed by CASOS at Carnegie Mellon University.²²

As Tomaso Venturini, Anders Munk, and Mathieu Jacomy usefully observe in this volume, STS scholars have engaged with network analysis methods in productive ways, at times finding a useful—if somewhat messy—convergence with actor-network theory’s idioms and aims. Here, my interest is to reflect on the type of insight networks might offer a design-ecological analysis. What type of design worlds do networks describe? What types of questions might they help us address?

A design-ecological analysis seeks to make visible the sociotechnical infrastructures at play in a design process, incorporating data as ethnographic material susceptible to both visual representation and quantitative analysis alongside other forms of observation and reflection. As Drieger notes, a network analysis seeks to progressively dig into the structure of the data and the relationships they inscribe in order to offer “topological insights” (2013), which might reveal high-level relational and hierarchical patterns in the data. Thus, a network approach to a design-ecological analysis has the potential to relate social actors and collectives such as design coordinators, tradespeople, and organizations with nonhuman ones such as concepts, ducts, columns, and software in ways that reveal hidden alignments and misalignments.

Figures 8 and 9 serve as illustrations of this approach. The networks in figure 8 are directed force graphs (Eades 1984) exploring the conflicts’ relationship with trades and building location. Design conflicts, represented as nodes, are connected to and clustered around their location and, depending on whether a second trade is involved in their resolution, can be linked to a second trade. A node representing a clash between a duct and a concrete beam in the “MEP” graph, for example, would be connected both to its location in the project (building 1, building 2, etc.) and to the node representing the “concrete” trade. Because conflicts involving one trade are connected only to (and clustered around) their location, these graphs show two levels of clustering.

The networks in figure 9 follow a similar principle, but explore a different type of relationship. This visualization is produced by computationally analyzing the



FIGURES 6 AND 7: The two maps on top represent the incidence of conflicts on a specific area geometrically by scaling a shape. The ones on the bottom do so through color. Each set comprises two different images representing different dates in the design process.

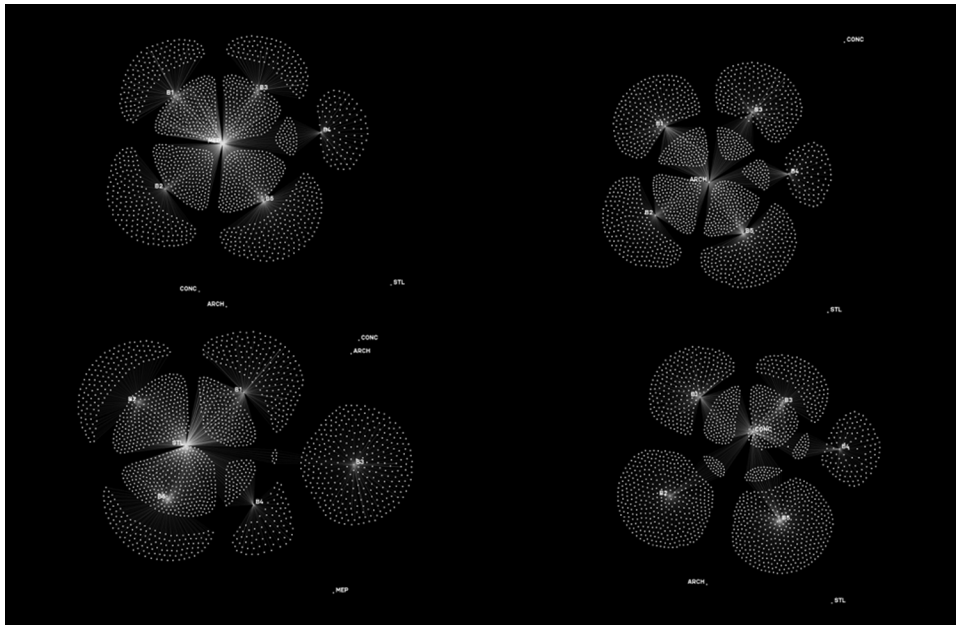


FIGURE 8: Directed force graphs representing placing design conflicts as nodes in relation to building location, main trade, and secondary trade.

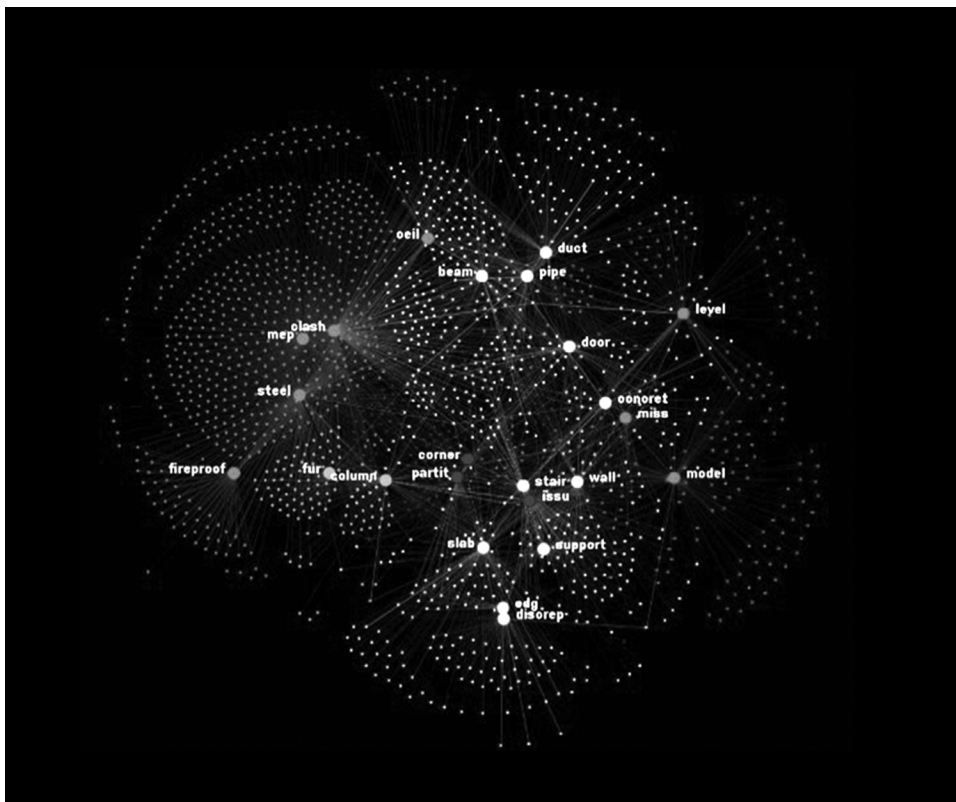


FIGURE 9: Text analysis reveals a network of recurring concepts overlapping the conflict graph.

description field of each conflict, “mining” the dataset for words that repeat over a certain threshold (50 or more appearances in the dataset) and discarding “stop-words” such as prepositions and articles. The resulting graph can be read as an elaboration of the meta-network in figure 8. Along with the trades and buildings, 24 “stem” words are represented as nodes and placed in relation to the trade and building clusters, offering insight about concepts and concerns having an impact on the process of coordination in different areas of the project and in different organizations. Relative to the examples discussed in the previous sections, network visualizations mobilize more complex methods and pack greater assumptions about the data. A detailed discussion of these experiments and their potential role in design-ecological analyses will be the subject of a forthcoming publication. Design-ecological networks explore relationality across concepts, spaces, and people.

Conclusion

A premise of this chapter has been that modes of design structured by technologies such as software, simulations, and numerically controlled machines require that we expand our descriptive and analytical capacities as scholars. The limits of design, usually circumscribing conceptual and representational work, stretch here to incorporate large collectives, sociodigital infrastructures, and relations. In this chapter, I have shown how we might go about making these infrastructures visible in ways that help challenge popular and disciplinary narratives about individual authorial agency and extend the reach of our historiography and ethnography of design. Accordingly, the chapter has outlined a method for design-ecological analysis that, as shown, incorporates the ephemeral data of design as ethnographic materials susceptible of both visual representation and computational analysis in ways that complement and rely upon other forms of observation and reflection.

My argument has hinged on a case study, the collaborative design coordination of a large architectural project, which I traced ethnographically through the observation of both social and digital transactions. In the assemblage work of creating a building’s digital model, coordinators produce a design representation—a BIM—where the efforts of multiple people, systems, and organizations converge. The toil of coordination is realized in the efforts by a team of BIM coordinators to collect, translate, aggregate, inspect, report, and act upon thousands of design conflicts. Making visible a constantly changing landscape of design conflicts and indexing their coordination to various spatial, temporal, and conceptual parameters, these visualizations are illustrations of the condition I term design-ecological.

These visualizations inscribe epistemic commitments and carry interpretive force. While a visualization of design as a radial tree reinforces ideas about hierarchy and central control in design, a visualization of design as a dynamic system akin to a meteorological event suggests an open-ended, organization-agnostic reading. A spatial representation relating conflicts to locations in physical space has the capacity to situate seemingly abstract datasets within material and spatial contexts, rekindling material objects in space with the managerial processes that modulate their production. Network visualizations mobilize significant algorithmic capacities to flexibly generate high-level topological insights relating design conflicts with concepts, spaces, and organizations. We may consider these *trees*, *maps*, *fields*, and *networks* as interpretive components of a fledgling visual discourse

about design ecologies—components we may tactically choose with descriptive, critical, or speculative intents.

And yet, as we have seen, their evocative power is realized in conjunction with other methods of observation and analysis, and with a critical understanding of the actions surrounding their very design and implementation. Accordingly, data collection is best understood as a type of intervention, and data visualizations as situated artifacts with their own sociomaterial histories. An effective design-ecological analysis must thus put them in conversation with different forms of observation, reflection, and self-reflection. By making the dataset open, I hope that other researchers will investigate alternative ways to visualize this particular design ecology and offer other insights and alternative readings.²³

We are left with both questions and avenues to future work. Tracing design ecologies can help us make visible forms of technical work emerging from contemporary modes of design production. It can help us see creative practices through a lens that puts social, material, and technological infrastructures—and the labors that sustain them—in focus as integral rather than subsidiary to the phenomenon of design. For reasons including the importance of delineating a political ecology of design, this is a worthy endeavor.²⁴ How may we trace design ecologies in ways that reveal a broader spectrum of contentions, conflicts, and their resolutions? How may we further trace situated and performative accounts of design in ways that challenge central, panoptic views?

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Notes

1. Ecology already offers what cultural geographer Matthew Gandy has termed “an ontology of interconnectedness” to a range of fields such as biology, where the term originated, to other scientific and urban fields, where it has been used, ambivalently, both because of its biophysical meaning and “as a tool for understanding the capitalist urbanisation” (2015, 150). Brought into design, ecology invites a conceptualization of its practice as a set of interdependent sociotechnical and material relations.
2. For more details and an expanded discussion of the larger study from which this project stems, see Cardoso Llach (2015).

3. For detailed introductions to BIM, see Eastman et al. (2011); for architectural perspectives highlighting its potential for architects, see Deamer (2012), Tombesi (2002), and Deutsch (2011); for critical perspectives, see Dossick and Neff (2011) and Cardoso Llach (2015).
4. See (Cardoso Llach 2015, 49–72).
5. This shift was enabled by the late 20th-century increase of computers' and software's processing, storage, and display capacities, which made interactive and highly detailed three-dimensional models possible. These advances notwithstanding, paper drawings remain the legally binding documents in the building industry and the chief means of communication between designers and builders on site.
6. File formats, software applications, and other information standards are often specified contractually. While industry and academic consortia have for years sought to establish a standard digital format, these efforts have not resulted on an industry-wide file format (Eastman et al. 2011; Deutsch 2011). For an expanded discussion of file format standardization, see Cardoso Llach (2017).
7. For a history of IFC, see Mikael Laakso (2012).
8. BIM is purported to greatly reduce what is often termed in this industry as “interoperability costs” (Gallaher et al. 2004). For example, a now often reviled but until recently common coordination practice was to reconstruct a given model or drawing in order to insert it into the central model.
9. Compatibility issues between different software platforms are known in the industry as “interoperability problems.” According to some scholars, these problems are a major cause of inefficiency and waste in the industry. For example Gallaher and collaborators (2004) quantify the cost of this inefficiency as \$15.8 billion.
10. Examples include interpretive work on data such as museum and library collections (Deschner and Dulin 2015), historical and geospatial narratives (Spatial History Project 2016; Bhawsar and Ray 2016), films (Manovich 2013), as well as, more recently, social media content (Tifentale and Manovich 2015).
11. Researchers in human-computer interaction have studied traces such as byproducts of online activity including social media exchanges (Schwanda et al. 2012; Peesapati et al. 2010), credit card transactions (Schwarz et al. 2009), and Wikipedia collaborations (Viégas et al. 2006). More generally, digital traces may include time stamps in version-controlled software projects, records of data entries in a database, (certain kinds of) sensor data, and patterns of interface usage within software environments. Geiger and Ribes propose “trace ethnography” as a methodology combining the examination of traditional ethnographic subjects with trace data (2011, 1).
12. An exception is the recent work by Albena Yaneva (2016), with which the work I present in this chapter shares some methods as well as aims.
13. Users engage software tools in different and idiosyncratic ways. Observing how scientists use PowerPoint and Photoshop to communicate visually, Janet Vertesi notes how their use of visual tools may reflect different professional sensibilities and understandings of the problem at hand (Vertesi 2009, 175).
14. In retrospect, it would have been possible to approach this problem differently, simply “cleaning the data” after collection (a process sometimes referred to as data “wrangling”). This would have likely involved a different kind of effort—entailing a significant effort to edit the data manually or semiautomatically.
15. They are an example of what digital media scholar Yanni Loukissas usefully terms, in this volume, “local data.”
16. In “Seamful Spaces,” Janet Vertesi usefully articulates the term “seamful” to address a concern with “multiple, coexisting, nonconforming infrastructures” in sociotechnical systems (Vertesi 2014). Human-computer interaction (HCI) researchers have used the term to acknowledge disparities and dissimilarities between the different components of a technological system (Weiser 1995; Chalmers and Maccoll 2003). I borrow the term here to refer to data's multiple, heterogeneous, and plural nature.
17. Historian and sociologist David Turnbull has used the expression “knowledge spaces” to describe situated social and material building practices. For example, communities of artisans building a Gothic cathedral configure a “knowledge space,” or a “contingent assemblage of local knowledge” (Turnbull 2000, 6).
18. Many in the project confronted BIM coordination with skepticism. The worlds of building production can be ruthlessly pragmatic and little inclined to introduce technological changes into long-standing traditions of trust building, work, verbal communication, and nondigital representation

- media. For an extended discussion of how engineers, architects, and tradespeople engaged in “generative forms of resistance” toward BIM in this project, see Cardoso Llach (2015, 121–48).
19. Proposing the term *capta* as a substitute for *data*, Drucker calls our attention to the codependence between observer and that which is observed, calls for site-specific interpretations, challenges direct readings of statistical generalizations, and helpfully situates data visualizations against broader cultural and historical frames (Drucker 2014).
 20. In recent years work in the fields of computer science and HCI has sought to specify visual analytics as a scientific field addressing a combination of large datasets, interactive displays, and uncertain information. A premise of this approach, framing the high volume and diversity of data as a concern for cognitive task performance and human decision making, is that large volumes of data pose challenges to individuals and groups in critical scenarios such as emergency management and conflict resolution (Arias-Hernandez et al. 2011). Not surprisingly, this line of research has been largely shaped by (and funded by agencies concerned with) national security concerns such as the “threat of terror” and emergencies resulting from natural disasters, particularly by the US Department of Homeland Security (Kielman et al. 2009; Thomas and Cook 2005). Similarly, the US Office of Naval Research (ONR) has supported efforts in the related field of information visualization (Card et al. 1999, 14). As these security-minded perspectives shape the field of visual analytics, interactive data visualization tools appear chiefly as means to improve analytical efficiencies over large sets of “spatio-temporal intelligence,” weather, and other applications affording the United States the capacity for *faster* and *more appropriate* action. Crucially, recent revelations that the US government routinely collects large swathes of citizen data, including phone and email metadata, raise questions about the role of these technological practices in eliciting the erosion of citizens’ rights to privacy under the guise of supposedly unquestionable security concerns.
 21. This visualization was first discussed in Cardoso Llach (2012b, 2012a) and subsequently elaborated in Cardoso Llach (2013).
 22. I am grateful to Javier Argota Sánchez-Vaquerizo for his research assistance, crucial to using the CASOS software and to producing the network visualizations presented here.
 23. An anonymized version of the dataset and the source code for the different visualizations can be downloaded at <https://github.com/dcardo/Visualizing-Traces/>.
 24. See Latour (2004).

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