

Joint Center for Housing Studies
Harvard University

Digitalization and Housing
**Framing Paper for “Bringing Digitalization Home:
How Can Technology Address Housing Challenges?”**

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The symposium “Bringing Digitalization Home: How Can Technology Address Housing Challenges?” was hosted by the Harvard Joint Center for Housing Studies in March 2022 and funded by Qualcomm. Participants examined the changes that digitalization—the use of automated digital technologies to collect, process, analyze, distribute, use, and sell information—is spurring in the way housing is produced, marketed, sold, financed, managed, and lived in.

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Abstract

Digitalization—the strategic use of technologies that collect, create, process, organize, analyze, use, and monetize data—is changing the ways that housing is produced, marketed, sold, financed, managed, and used in the United States and abroad. These changes have potential to advance—or hamper—efforts to address pressing housing-related economic, social, and environmental challenges, including affordability, segregation, discrimination, gentrification, displacement, resiliency, climate change, changing demographics, citizen participation, equity, and privacy.

Given digitalization’s potential to both alleviate and exacerbate key challenges, there is a critical need to better understand the ways digitalization is changing housing; to assess the impact of those changes; and to explore strategies that would better harness the energy behind the changes to help address key economic, social, and environmental challenges. To spur the discussions on these issues, the Harvard Joint Center for Housing Studies commissioned 11 papers examining how digitalization is affecting key aspects of housing. In March 2022, the papers’ authors presented them at a symposium held at the Harvard Graduate School of Design. The Center is publishing revised versions of those papers on its website.

This framing paper helps set the stage for those papers by providing background on the digital revolution and on digitalization generally. We then turn to discussions about how digitalization is transforming many key aspects of housing, whether those changes are likely to produce private benefits for those who develop and finance them, and whether they will further key public goals. Drawing on this discussion, we then cover broad approaches that might harness the energy and resources behind these changes to address key challenges (or at least reduce the likelihood that digitalization will exacerbate key problems). We conclude with a summary overview of how authors of the commissioned papers assessed key changes and their ideas on whether and how public, private, and civic actors might respond to those changes. We then draw on these assessments to offer concluding thoughts about the changes, their impacts, and potential responses to them.

Overview

Digitalization—the strategic use of technologies that collect, create, process, organize, analyze, use, and monetize digitalized data—is transforming the ways that housing is produced, marketed, sold, financed, managed, and used in the United States and abroad.

Illustratively, the growing numbers of large-scale investors that use digitalized technologies to find, buy, rent, and manage a growing number of single-family homes is having a dramatic effect on many local real estate markets while platforms like Zillow and craigslist have changed the ways that people search for homes to buy or rent. Entities like Rocket Mortgage and loanDepot have changed the ways that people search for and get mortgages, while automated underwriting tools used by entities like Fannie Mae and Freddie Mac have transformed the ways those mortgages are reviewed and approved. Tools like Alexa, Google Home, and Siri are changing the ways that we live in our homes. And more change may be coming: between 2019 and 2021, firms focused on technology and real estate received almost \$90 billion in venture capital funding, substantially more than in the previous five years.¹

The economic opportunities are, in fact, enormous: in 2021, expenditures on housing—including the construction of new single-family and multifamily structures, residential remodeling, production of manufactured homes, brokers’ fees, gross rents and utilities paid by renters and owners’ imputed rents and utility payments—totaled about \$3.9 trillion, about 17 percent of the nation’s total gross domestic product.² Given the slow pace of change in areas like construction, digitalization clearly has the potential to reduce costs in key aspects of housing, and in doing so, to make housing more affordable. Moreover, it has the potential to help address a variety of other housing-related economic, social, and environmental challenges. For example, by making it easier to learn about homes for sale or rent or by making it easier to objectively assess mortgage applications, digitalization could help address longstanding patterns of racial and ethnic discrimination and segregation in housing. Similarly, by eliminating face-to-face interactions with lenders, automated underwriting could end, or at least greatly reduce, biased decision-making in the mortgage approval process. And by making it easier to monitor and control energy uses in the home (and also to manage an increasingly decentralized power grid),

¹ Center for Real Estate Technology + Innovation, “2021 Real Estate Tech VC Funding Report,” CRETI, 2–4, accessed January 13, 2022, <https://creti.org/2021-real-estate-tech-vc-funding-report>.

² “Housing’s Contribution to Gross Domestic Product - NAHB,” accessed March 8, 2022, <https://www.nahb.org/news-and-economics/housing-economics/housings-economic-impact/housings-contribution-to-gross-domestic-product>.

digitalization could play a significant role in efforts to reduce greenhouse gas (GHG) emissions from the residential sector, which is responsible for about a quarter of energy consumption in the United States.³

At the same time, however, growing use of digitalization by private entities involved in housing could exacerbate longstanding problems because there is no guarantee that the cost savings created by digitalization will be passed onto consumers. Moreover, in some cases digitalization may not reduce costs. Instead, it may mainly reallocate benefits, such as when investors buy existing multifamily properties with moderately priced units, upgrade those units, and charge significantly higher rents. Along these same lines, investors using advanced analytic tools are changing many local housing markets in ways that could weaken efforts to close historically large racial homeownership gaps. Algorithms used to target potential buyers and renters could continue historic patterns of residential discrimination; algorithms used to assess mortgage applications could perpetuate historic patterns of discrimination in lending. And the increased collection of personal data by a host of applications raises important concerns about privacy. Given digitalization’s potential to both alleviate and exacerbate key challenges, there is a critical need to better understand the ways digitalization is changing housing; to assess the impact of those changes; and to explore strategies that would better harness the energy behind the changes to help address key economic, social, and environmental challenges, as well as approaches that might limit potential harms.

To stimulate these discussions, the Joint Center for Housing Studies, with support from Qualcomm, Inc., commissioned eleven papers by leading researchers familiar with how digitalization is changing (or could change) practices in five key areas:

- The ways that housing is designed and built
- The ways that investments are made in housing
- The ways that housing is planned, reviewed, and regulated
- The ways that people find and finance housing
- The ways that housing is used

We asked those authors—as well as the researchers, practitioners, policymakers, and civic leaders who commented on the papers—to focus on three central questions:

³ “Monthly Energy Review” (U.S. Energy Information Administration, 2022), 37, <https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf>.

1. How is digitalization changing—and how is it likely to change—a specific aspect of housing and housing markets?
2. Are these changes likely to further, or hamper, efforts to address pressing housing-related economic, social, and environmental challenges, such as affordability, equity, opportunity, resiliency, climate change, changing demographics, and privacy?
3. How might the public, private, and non-profit sectors harness the forces behind the changes to produce more equitable and environmentally beneficial outcomes?

Authors presented preliminary versions of their papers at a March 2022 symposium held at the Harvard Graduate School of Design and online. Other researchers, as well as practitioners, policymakers, and others familiar with the changes commented on the presentations. Authors then revised their papers, which are being published as Center working papers.

This framing paper, which sets the stage for the commissioned papers, begins with three background sections: “The Digital Revolution,” “Key Aspects of Digitalization,” and “Concerns About Digitalization.” We then turn to how digitalization is affecting housing in sections that first detail “Digitalization’s Growing Impact on Housing,” and then offer “A Framework for Assessing Digitalization’s Impacts on Housing,” which we used to structure the symposium and asked authors to use as they examined how digitalization is affecting different aspects of housing. The penultimate section, “An Overview of Papers Commissioned for the Symposium” briefly summarizes their assessments. Finally, a short concluding section, “Moving Forward,” offers some thoughts about the changes, their impacts, and potential responses to them.

The Digital Revolution

In the 1950s and early 1960s, when large mainframe computers first became available for commercial use, some corporations initially began using them to automate tasks, like payroll processing, that had been done manually. However, their high cost, large size, and relatively slow processing speeds generally limited their use to large, well-financed entities. Of course, that changed dramatically over the subsequent decades because, as Intel co-founder Gordon Moore famously and accurately predicted in the 1960s, the processing power of computers would double about every two years while their price would drop by about 50 percent.⁴ Those trends, which also made it possible to pack more and more

⁴ Moore’s original article, which focused on the number of transistors that could be produced on a single circuit, predicted the change would occur annually. See Gordon E Moore, “Cramming More Components onto Integrated

computer power into smaller and smaller devices, spurred a revolution marked by the emergence of desktop computers in the 1980s, laptop computers and the internet in the 1990s, smart phones in the 2000s, and tablets and smart home devices in the 2010s.

The growth in computing power and our ability to use that power has transformed the ways that information is collected, created, stored, analyzed, and shared. Notably, as late as the mid-1980s, roughly three decades after the first businesses in the US started using mainframe computers, virtually all information was still being stored in analog forms, according to Martin Hilbert, a computational social scientist. However, between 1986 and 2014, the world's ability to create digitized data grew by about 60 percent annually, while the capacity for transmitting data grew by about 35 percent a year and total storage capacity grew by about 30 percent annually.

The Dramatic Shift to Digitized Data

Despite this technological growth, as of 2000, only about a quarter of the world's information was stored in digital form. However, by 2007 more than 90 percent was stored in digital form and, by 2010, virtually all of it was in a digital form.⁵ This stunning shift to digitized data was driven not only by increases in computing power (and concurrent reductions in costs) but also by important changes in the ways that computing power has been deployed. One key change involves Application Programming Interfaces (APIs), which "make it possible for digital devices, software applications, and data servers to talk with each other," specifically to provide "the raw data and other machine-readable information needed behind the scenes to put the resources being delivered to work, with very little assistance from a human."⁶ While software developers had been using APIs for some time, in the early 2000s a host of innovative web-based platforms, such as Amazon, Facebook, Apple, Salesforce, eBay, Flickr, and Twitter, rolled out programs that, making use of APIs, allowed third-party developers to create applications that integrated the information that multiple platforms had about their users.

Circuits," *Electronics* 38, no. 8 (April 19, 1965): 4; Dylan Tweney, "April 19, 1965: How Do You Like It? Moore, Moore, Moore," *Wired*, April 19, 2010, <https://www.wired.com/2010/04/0419moores-law-published/>.

⁵ See Martin Hilbert and Priscila López, "The World's Technological Capacity to Store, Communicate, and Compute Information," *Science* 332, no. 6025 (April 1, 2011): 60–65, <https://doi.org/10.1126/science.1200970>. For some updated estimates see Martin Hilbert, "The World's Technological Capacity to Store, Communicate, and Compute Information," *MartinHilbert.Net* (blog), accessed July 9, 2021, <https://www.martinhilbert.net/worldinfocapacity-html/>; "Information & Communication Quantity," *MartinHilbert.Net* (blog), accessed February 22, 2022, <https://www.martinhilbert.net/information-communication-quantity/>.

⁶ Kin Lane, "What Is an API and How Does It Work?," Postman Blog, October 5, 2020, <https://blog.postman.com/intro-to-apis-what-is-an-api/>.

As Sarah Barns, a leader in the emerging field of “platform urbanism,” notes in her detailed discussion about the role that APIs played in the growth of transformation of Facebook,⁷ the developers were attracted by the access these tools gave them to potential customers; the growth of offerings on successful platforms that attracted more users; and the potential for the entities that controlled the platforms (and the data they both collect and create) to grow more powerful and more profitable. The result, she adds, has been “a highly active ecosystem of users and producers, software developers and marketers, drivers and riders, all governed by the terms of engagement set out by the platform and its API [that] generates beneficial, if not always equal, network effects for its participants.”⁸

The power of APIs was further enhanced by the development of cloud computing with the launch, in 2006, of what is now Amazon Web Services, which made it easier and cheaper for a host of entities to access digital resources. The extent and reach of these tools greatly expanded a year later, when Apple released the first iPhone and Google released Android, an open source mobile platform. Smart phones, in turn, have been followed by the internet of things, the network of sensors, software, and other technologies that link physical objects (ranging from items found in most household objects to sophisticated industrial tools) to the internet, which allows them to collect and share data with other devices and host systems.”⁹ This shift, notes digital strategist Kin Lane, has “opened up entirely new frontiers when it comes to how we create, transmit, store, and share data online.”¹⁰

The last factor fueling the digitization of the world’s data is the growing ability to analyze that data in timely and useful ways, particularly via techniques like AI, machine learning, and other forms of data mining that are enabled by the advances in computing power. This step, Hilbert has noted, is critical especially in light of the fact that much of the new data comes from disparate, and often untraditional sources, as well the fact that it is available in real time. For all these reasons, Hilbert contends, “the full name of Big Data is Big Data Analytics.”¹¹

⁷ Sarah Barns, *Platform Urbanism: Negotiating Platform Ecosystems in Connected Cities*, Geographies of Media (Singapore: Springer Singapore, 2020), 43–48, <https://doi.org/10.1007/978-981-32-9725-8>.

⁸ Sarah Barns, “We Are All Platform Urbanists Now,” accessed January 14, 2022, <https://www.mediapolisjournal.com/2018/10/we-are-all-platform-urbanists-now/>.

⁹ This definition draws on “What Is the Internet of Things (IoT)?,” Oracle, accessed September 8, 2022, <https://www.oracle.com/internet-of-things/what-is-iot/>.

¹⁰ Kin Lane, “Intro to APIs: History of APIs,” Postman Blog, October 10, 2019, <https://blog.postman.com/intro-to-apis-history-of-apis/>.

¹¹ Martin Hilbert, “Big Data for Development: A Review of Promises and Challenges,” *Development Policy Review* 34, no. 1 (January 2016): 6, <https://doi.org/10.1111/dpr.12142>.

Key Aspects of Digitalization

The rapid and dramatic growth of digitized data and the firms that create and use it underscores the value, power, and importance of "digitalization"—the strategic decisions involving how digitized data is collected, created, processed, organized, analyzed, used, and monetized.

Collecting and Creating Digitized Data

Sometimes, digitalization involves the conversion of information previously (or currently) held in analog forms, such as information about the ownership, value, and size of residential structures found in countless registries of deeds, building departments, and assessor's offices. The growth of computing power made it possible for Zillow, which was founded in 2005, to digitize all this information and assemble it in one place. Doing so, notes digital strategist Russell Walker, was "a massive undertaking [that] required accessing and updating information from various counties, cities, states, including new transactional data on sales, and even linking to widely available datasets such as Google Streetview and Google Maps."¹²

As previously noted, digitalization also involves the creation of new forms of information. The growth of digital platforms, fueled in large measure by the use of APIs, makes it possible to collect vast amounts of information about people who visit a platform or leverage applications created by third-party developers. Airbnb, for example, generates recommendations about future rentals based in large measure upon what it knows about users' previous searches.

Processing and Organizing the Information

While it may appear simplistic, the value of digitalization comes from the fact that computers not only make it easier to collect important information but also to organize it in ways that make it easier to find and use. Consider, for example, real estate broker David Meek's account of how realtors and potential homebuyers learned about properties for sale in the mid-1980s, in the era before online listings. "Before the web, the real estate industry was powered by catalogs [that] resembled the *White Pages* or a black-and-white Sears catalog," he wrote. These weekly publications had information about properties for sale and recently sold properties, all presented in picture-less, small-font, blurbs that were full of abbreviations. Moreover, they were expensive, so each office tended to get just one copy. "'Book Day' was every third Wednesday around my office," he recalled. "... It was almost a minor holiday for buyer

¹² Russell Walker, *From Big Data to Big Profits: Success with Data and Analytics* (New York: Oxford University Press, 2015), 98.

clients and many real estate agents. Realtors in our conference room looked like medieval monks carefully transcribing text from a sacred book onto parchment. When it later became available, the online MLS was the technological equivalent of the Gutenberg Press to the old manuscripts.”¹³ The online MLS, of course, made it easier for realtors but not potential buyers to access this information. Indeed, Zillow was founded, in part, with the idea of making it easier for homebuyers and homeowners to access this information, much as Expedia (which had been co-founded by one of Zillow’s founders) made it easier to access information about airfares and hotel rates that previously had only been accessible to travel agents.¹⁴

In a somewhat similar vein, since the mid-1980s, Computer-Aided Design and Drafting (CADD) and Computer-Aided Design and Computer-Aided Manufacturing (CAD/CAM) programs developed by firms like Autodesk have made it much easier for architects and designers to access information about key components as they design buildings, and to share that information with builders, owners, and occupants. And in the late 1980s and 1990s, many planners and natural resource managers began using new, proprietary Geographic Information Systems (GIS) developed by entities like the Environmental Systems Research Institute (ESRI) and Earth Resources Data Analysis System (ERDAS). These proprietary systems store, retrieve, analyze, and visualize digitized geographic information produced by public agencies and other entities, such as the US Census Bureau, which started producing digitized mapping information in the 1960s.¹⁵ The secondary mortgage market underwent a very similar transition. In the early 1980s until the mid-1990s, that market “relied almost exclusively on delegated underwriting, in which thousands of lenders with tens of thousands of mortgage underwriters followed their own written standards and the voluminous guidelines of Fannie Mae or Freddie Mac (or those of similarly functioning counterparts for non-conforming loans),” recalled John Straka, who was the director of consumer modelling at Fannie Mae. By the late-1990s, much of that process had been automated.¹⁶

¹³ David Meek, “What Did the MLS Look Like in 1985?” *The Arizona Report™* (blog), May 6, 2019, <https://arizonareport.com/mls-books/>.

¹⁴ Walker, *From Big Data to Big Profits*, 98.

¹⁵ William J. Drummond and Steven P. French, “The Future of GIS in Planning: Converging Technologies and Diverging Interests,” *Journal of the American Planning Association* 74, no. 2 (April 24, 2008): 165, <https://doi.org/10.1080/01944360801982146>.

¹⁶ John W. Straka, “A Shift in the Mortgage Landscape: The 1990s Move to Automated Credit Evaluations,” *Journal of Housing Research* 11, no. 2 (2000): 209.

Analyzing Digitized Data

Digitalization's great power, of course, comes from the ways that it facilitates analyses of information. While the growth of "big data" and "big data analytics" have brought this aspect to the fore, such analyses have been at the heart of how digitalization has been transforming housing and much of the rest of the modern society for several decades. Illustratively, GIS systems developed by entities like the ESRI and ERDAS were so useful to planners that their use rose from less than 10 percent of all local governments in 1985, to 20 percent in 1990 and almost 90 percent in 1997.¹⁷ The rapid adoption, wrote planners William J. Drummond and Steven P. Francis, was due to the fact that "the fit between GIS and the needs of local planners was excellent. Planners had professional interest in environmental issues, long-term commitments to particular geographic areas, and access to governmental computing resources. They also understood maps and had pressing needs to conduct complex geospatial analyses that were beyond the capabilities of simple computer mapping programs."¹⁸

A variety of computer-created analyses also transformed key aspects of real estate investment and finance, notes Andrew Baum, a longtime real estate investor who taught at the University of Oxford's Saïd Business School. "The growth of indirect private fund vehicles with different styles, debt and asset-backed securitisation, the arrival of REITs, the growth of a derivatives market ... fed on and demanded a much more quantitative and research-focused approach to performance measurement and investment strategy," he wrote in "PropTech 3.0: The Future of Real Estate," a widely cited 2017 report. In addition, "the rapid globalisation of the real estate industry in terms of investors, sources of capital and advisory services substantially reduced the insularity of the industry and brought increased demands for a more research-led product. Growing data availability enabled more finance-grounded quantitative modelling, and valuation software and property and portfolio management systems became computer and technology based."¹⁹

¹⁷ Liza Warnecke et al., "Geographic Information Technology in Cities and Counties: A Nationwide Assessment" (Chicago: Urban and Regional Information Systems Association, n.d.), 23, https://www.urisa.org/clientuploads/directory/Documents/Books%20and%20Quick%20Study/cities_and_counties.PDF.

¹⁸ Drummond and French, "The Future of GIS in Planning," 164–65.

¹⁹ Andrew E. Baum, "PropTech 3.0: The Future of Real Estate" (Oxford: Oxford Future of Real Estate Initiative, Saïd Business School, University of Oxford, April 2017), 13, <https://www.semanticscholar.org/paper/PropTech-3.0%3A-the-future-of-real-estate-Baum/9837e5857a2f2f9f8d145d72158ae34ed9b6eaa4>.

All of these changes have intensified in the last two decades. Illustratively, lenders who, for decades, have used automated systems to assess applications for all forms of credit, including mortgages, are increasingly interested in using machine learning to develop new (and presumably better) models for credit underwriting.²⁰ Similarly, in 2018, a McKinsey & Company report on using big data in real estate noted that investors could identify potentially revealing “hyperlocal patterns” by making better use of “new and unconventional data sources,” such as mobile phone signal patterns, Yelp reviews of local businesses, the number of permits issued for swimming pools, or changes in the number of coffee shops. To do this, the report noted, firms could acquire software that used APIs to collect and prepare data for analyses and tools like machine learning and AI that “make it significantly easier to aggregate and interpret these disparate sources of data.”²¹

Using Digitalized Data

As the previous discussions make clear, virtually all key actors in housing can—and do—make use of digitalized data to make and carry out decisions about a host of fundamental questions related to housing such as what to build or buy, how to design and construct new residences or renovate old ones, whether those buildings should be approved, where to look for homes, whether to approve a mortgage application, and how a home should be used. Illustratively, automated underwriting has long been used to evaluate mortgage applications. More recently, a growing number of institutional investors, such as Progress Residential, are using computers to quickly identify and assess single-family homes just listed for sale. If a home meets certain criteria, firms will often make an all-cash offer within two hours of its initial listing. The properties are often converted to single-family rentals, and their owners rely on a host of online tools to handle everything from rental payments to maintenance requests.²²

²⁰ “The Use of Machine Learning for Credit Underwriting: Market & Data Science Context” (FinRegLab, September 2021), 8–9, <https://finreglab.org/ai-machine-learning/explainability-and-fairness-of-machine-learning-in-credit-underwriting/the-use-of-ml-for-credit-underwriting-market-data-science-context/>.

²¹ Gabriel Morgan Asaftei et al., “Getting Ahead of the Market: How Big Data Is Transforming Real Estate,” McKinsey & Company: Real Estate Insights, October 8, 2018, <https://www.mckinsey.com/industries/real-estate/our-insights/getting-ahead-of-the-market-how-big-data-is-transforming-real-estate>.

²² See Peter Whoriskey, Spencer Woodman, and Margot Gibbs, “This Block Used to Be for First-Time Homebuyers. Then Global Investors Bought In.,” *Washington Post*, December 15, 2021, <https://www.washingtonpost.com/business/interactive/2021/investors-rental-foreclosure/>. See also Desiree Fields, “Tech and Finance Firms Buying up Homes Doesn’t Bode Well for Everyone Else,” *Washington Post*, accessed February 13, 2022, <https://www.washingtonpost.com/outlook/2022/01/04/corporate-landlords-silicon-valley/>.

Monetizing Digitalized Data

Digitalization has also been marked by the growth of digital platforms that collect, organize, and analyze data about their users and then monetize that data by allowing advertisers and software developers to closely target users who come to the platforms and because they provide useful—and free—information and tools. As Nick Srnicek, one of the first to use the term “platform capitalism” to describe this important shift, has noted, while there are several types of platforms and different platforms have different strategies, “in every case, collecting massive amounts of data is central to the business model and the platform provides the ideal extractive apparatus” for getting that data.²³

Broadly, this is the approach pioneered by Facebook and Google. Zillow, which was founded in 2005, is an especially noteworthy example of this approach in housing. As noted earlier, those who developed Zillow initially believed the site could replace realtors (much as travel agents were displaced by entities like Expedia). However, while most individuals start their housing searches on sites like Zillow, buying a home is such a complicated, large, and personal commitment that they usually wind up working with a real estate agent. Recognizing this, Zillow’s founders began selling advertisements to realtors and others, such as mortgage lenders, who wanted to connect with potential homebuyers. And by 2012, seven years after the site was launched, such advertising represented 75 percent of its revenues. A few years later, Zillow used its analyses to move into new lines of business, including an iBuying program that ultimately lost about \$1 billion before it was shut down in late 2021.²⁴ The demise of that program is sending Zillow back to its roots, according to Mike DelPrete, a leading analyst of online entities like Zillow, who wrote a paper for the symposium. Indeed, according to DelPrete, Zillow’s plans to more than double its revenues by 2025 rely on doubling revenues from agents advertising on the site and also by selling services such as mortgages and title insurance to the site’s users.²⁵

Digitalization’s Impacts

Taken together, the forces driving digitalization have transformed all aspects of modern life, often in ways that have expanded choices and reduced costs for many users. Taken as a whole, the scope of

²³ Nick Srnicek, *Platform Capitalism*, Theory Redux (Cambridge, UK: Polity, 2017), 89–90.

²⁴ This paragraph on Zillow draws on Walker, *From Big Data to Big Profits*, 98–100; Mike DelPrete, “2021 Emerging Models in Real Estate Report,” July 2021, 114–22, <https://www.mikedp.com/articles/2021/7/5/the-2021-emerging-models-in-real-estate-report>; Mike DelPrete, “Zillow Exits iBuying — Five Key Takeaways,” accessed February 13, 2022, <https://www.mikedp.com/articles/2021/11/3/zillow-exits-ibuying-five-key-takeaways>.

²⁵ Mike DelPrete, “Zillow 3.0: Back to Basics,” February 14, 2022, <https://www.mikedp.com/articles/2022/2/14/zillow-30-back-to-basics>.

these changes is stunning. As of December 2020, the combined market capitalization of Alphabet-Google, Amazon, Apple, and Facebook—four companies at the heart of the platform economy—exceeded \$5.7 trillion, an amount that is “greater than the market capitalization of the entire Euronext stock exchange and a third of the value of the whole Standard & Poor's 100 index of United States stocks.”²⁶ Such figures show that the changes wrought by digitalization are nothing less than a “fundamental reconfiguration of our economy” that “arguably [is] as momentous as the Industrial Revolution, reinventing capitalism as we know it,” as Victor Mayer-Schönberger and Thomas Ramege wrote in *Reinventing Capitalism in the Age of Big Data*, a widely cited 2018 book.²⁷ Echoing that theme, Klaus Schwab, founder and CEO of the World Economic Forum, has contended that the changes represent a “Fourth Industrial Revolution” that is “disrupting almost every industry in every country.”²⁸ “Like the revolutions that preceded it,” Schwab added, the current transformation has “the potential to raise global income levels and improve the quality of life for populations around the world.”

Concerns about Digitalization

However, as a variety of observers have noted, the changes can also have significant downsides. For example, Schwab, who would hardly qualify as a radical, has cautioned that the changes wrought by digitalization could “yield greater inequality,” which, in turn, could lead to “an increase in social tensions” as well as “democratic malaise.”²⁹ In particular, the rise of digitalization has given rise to four broad concerns: monopoly power, replicating and reinforcing current power dynamics, exacerbating and automating inequality, and losing privacy.

²⁶ Annabelle Gawer, and Nick Srnicek, *Online Platforms: Economic and Societal Effects*. (LU: European Parliament. Directorate General for Parliamentary Research Services., 2021), <https://data.europa.eu/doi/10.2861/844602>. See also Srnicek, *Platform Capitalism*.

²⁷ Viktor Mayer-Schönberger and Thomas Ramege, *Reinventing Capitalism in the Age of Big Data* (New York: Basic Books, 2018), 4.

²⁸ Klaus Schwab, “The Fourth Industrial Revolution: What It Means and How to Respond,” World Economic Forum, January 14, 2016, <https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/>. See also Klaus Schwab, *The Fourth Industrial Revolution*, First U.S. edition. (New York: Crown Business, 2017).

²⁹ Klaus Schwab, “The Fourth Industrial Revolution: What It Means and How to Respond,” World Economic Forum, January 14, 2016, <https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/>. See also Schwab, *The Fourth Industrial Revolution*, 2017.

Monopoly Power

To begin, as Fabian Braesemann and Andrew Baum have noted, while digitalization is likely to produce “efficiency gains... the benefits related to these gains are not likely to be distributed equally among those currently involved in the market.” Rather, they cautioned, “users and owners of real estate need to become aware of the potential value of data that are generated about tenancy agreements, energy consumption, or listing prices. Otherwise the benefits of datafication might be captured mostly by data-monopolists who offer complimentary apps and platforms to obtain real estate data for free from the users of their services.”³⁰

In fact, the nature of digital platforms makes it likely that the marketplace will be dominated by a relatively small number of firms. The issue, Srnicek explains, is that “digital platforms produce and are reliant on ‘network effects.’ ...The more numerous the users who use a platform, the more valuable that platform becomes for everyone else.” This, in turn, “generates a cycle whereby more users beget more users, which leads to a natural tendency towards monopolization.”³¹ Moreover, as Mayer-Schönberger and Ramge note, this process is exacerbated by the fact that the platforms also “use feedback data to learn,” which means that “the most popular products and services improve the most because they are fed the most data. In such a context, innovation is no longer about breakthrough ideas but rather about collecting the greatest amount of feedback data.” The result, they conclude, is that while network effects, feedback data, and economies of scale “have led to great advances in the kinds of products and services available on the market... they have also been driving concentration—the deadly poison for market efficiency.”³²

Replicating and Reinforcing Current Power Dynamics

A second concern, raised by the growing number of geographers, planners, and other scholars working under the rubric of “platform urbanism” or “platform real estate”³³, is that “just like all technology, PropTech is not simply a neutral technique or platform that replaces previously analogue systems.”

³⁰ Fabian Braesemann and Andrew Baum, “PropTech: Turning Real Estate Into a Data-Driven Market?,” *SSRN Electronic Journal*, 2020, 2–3, <https://doi.org/10.2139/ssrn.3607238>.

³¹ Srnicek, *Platform Capitalism*, 45.

³² Mayer-Schönberger and Ramge, *Reinventing Capitalism in the Age of Big Data*, 162–64.

³³ For more on platform urbanism and platform real estate see Barns, *Platform Urbanism*; Joe Shaw, “Platform Real Estate: Theory and Practice of New Urban Real Estate Markets,” *Urban Geography* 41, no. 8 (September 13, 2020): 1037–64, <https://doi.org/10.1080/02723638.2018.1524653>.

Rather, notes geographer Libby Porter, “data mined from consumer and purchasing patterns is being used to predict and in some cases manipulate, shape and even govern consumer choice, and at the same time shifting behaviors of actors in land and housing markets.”³⁴

Exacerbating and Automating Inequality

While the algorithms used in automated processes could, in theory, eliminate the implicit and sometimes explicit biases that individuals bring to decision making, they also could embed those biases in ways that are hard to detect and control, particularly in systems that rely on machine learning and AI to continually update key algorithms, such as automated valuation models (AVMs) used by an increasing number of lenders. However, a 2020 Urban Institute study by Michael Neal, Sarah Stochak, Linna Zhu, and Caitlin Young found that “AVMs in majority-Black neighborhoods produce larger errors, relative to the underlying sales price, than AVMs in majority-white neighborhoods.”³⁵ This disparity, the authors added, “suggest[s] that the expanded use of AVMs could disproportionately affect majority-Black neighborhoods and reinforce the impacts of past racial discrimination that often resulted in the undervaluation of Black-owned homes.”³⁶

Platforms have replicated historic patterns of discrimination in other important ways. Facebook, for example, has twice settled lawsuits related to the use of its algorithms in posts related to housing. In 2019, it settled a lawsuit, brought by National Fair Housing Alliance and other entities, which contended that Facebook’s targeted advertising tools allowed developers, real estate agents, lenders, and others involved with housing to target ads in ways that violated the Fair Housing Act as well as laws prohibiting discrimination in employment and lending.³⁷ In 2022, it settled a similar suit brought by the US Justice

³⁴ Libby Porter, “Planning, Land and Housing in the Digital Data Revolution,” *Planning Theory & Practice* 20, no. 4 (August 8, 2019): 576, <https://doi.org/10.1080/14649357.2019.1651997>.

³⁵ Michael Neal et al., “How Automated Valuation Models Can Disproportionately Affect Majority-Black Neighborhoods” (Washington, DC: Urban Institute, December 28, 2020), 1, <https://www.urban.org/research/publication/how-automated-valuation-models-can-disproportionately-affect-majority-black-neighborhoods>.

³⁶ Neal et al., 13.

³⁷ See *National Fair Housing Alliance v. Facebook, Inc.*, No. No. 18 Civ. 2689 (US District Court, Southern District of New York 2019), which was filed in March 2018 and settled in February 2019.

Department in the wake of a complaint initially filed by the US Department of Housing and Urban Development (HUD) only days after the 2019 suit was settled.³⁸

More broadly, Ben Green, a computer scientist focused on cities, has warned that as private companies “increasingly make decisions about individuals based on data drawn from online behavior and social networks,” lower-income people and those who are members of marginalized groups, “can be unfairly excluded from credit, jobs, housing and healthcare in ways that circumvent anti-discrimination laws.”³⁹ Similar concerns have been raised about the public sector’s growing use of computerized systems to identify and allocate resources for lower-income people and members of marginalized groups, such as coordinated care programs used to connect people experiencing homelessness with a wide but sometimes inchoate array of available services. While noting that such systems have helped many people who might otherwise not have known about them, political scientist Virginia Eubanks contends that “across the country, poor and working-class people are targeted by new tools of digital poverty management and face life-threatening consequences as a result.” Indeed, she claims, automated eligibility systems that were supposed to make it easier for poor and working-class people to access public benefits often “discourage them from claiming public resources that they need to survive and thrive.” The problem, she contends, is that “complex integrated databases collect their most personal information, with few safeguards for privacy or data security ... Predictive models and algorithms tag them as risky investments and problematic parents. [And] vast complexes of social service, law enforcement, and neighborhood surveillance make their every move visible and offer up their behavior for government, commercial, and public scrutiny” that often causes them to be denied access to needed services and resources.⁴⁰

Privacy and Access

In housing, as in other areas, there has been much discussion and debate about both legal and illegal access to, and uses of, data. As Porter notes, “Who is collecting this data from Apps and other

³⁸ See “Justice Department Secures Groundbreaking Settlement Agreement with Meta Platforms, Formerly Known as Facebook, to Resolve Allegations of Discriminatory Advertising,” The United States Department of Justice, June 21, 2022, <https://www.justice.gov/opa/pr/justice-department-secures-groundbreaking-settlement-agreement-meta-platforms-formerly-known>; Settlement Agreement, United States of America v. Meta Platforms Inc. f/k/a Facebook Inc., No. 1:22-cv-05187 (U.S. District Court Southern District of New York June 21, 2022).

³⁹ Ben Green, *The Smart Enough City: Putting Technology in Its Place to Reclaim Our Urban Future*, Strong Ideas Series (Cambridge, Massachusetts: The MIT Press, 2019), 98.

⁴⁰ Virginia Eubanks, *Automating Inequality: How High-Tech Tools Profile, Police and Punish the Poor*, First Edition. (New York, NY: St. Martin’s Press, 2018), 11.

processes? Who can access it? To what uses is it put and in whose interests? Recent concerns with Facebook and Google suggest that there is much *more* going on here than the regulation of individual data protection rights and ownership would solve. These are wide and deep questions of governance and power, as it is precisely this data which is creating new opportunities for accumulation. As the saying goes among social media users: if you are not being sold a product, you are the product.”⁴¹

In addition, there are widespread concerns about the security of the massive amounts of personal data collected by various entities, especially (but not exclusively) those related to smart homes and the internet of things. Computer scientist Avi Rubin, who is part of a multi-university consortium examining these issues, for example, has noted: “The current state of affairs in smart home security and privacy is dismal... These vulnerable systems often present easy targets for malicious attackers who can utilize them as platforms for further intrusion into the home network, for participation in botnets, and for ransomware attacks. An increasing number of home appliances and devices are 'smart,' and the result is a much wider attack surface in the home.”⁴²

Digitalization’s Growing Impact on Housing

As the previous discussion makes clear, digitalization already has dramatically changed all key aspects of housing. Moreover, if investment trends are any guide, the size and pace of change may greatly increase in the next few years. Notably, in 2014 VC firms reportedly invested only \$5 billion in what is often referred to as “PropTech” or, sometimes, “Real Estate Tech.” Funding increased steadily for the next several years before rising sharply to \$31 billion in 2019. VC investment fell slightly in 2020 but rebounded to a record \$32 billion in 2021—with about 70 percent of the funding going into firms focused on housing and another 19 percent on those focused more broadly on some aspect of construction.⁴³ And while some of the growth in total funding was due to increases in overall VC activity,

⁴¹ Porter, “Planning, Land and Housing in the Digital Data Revolution.”

⁴² Doug Donovan, “Securing Smart Homes,” *Johns Hopkins Magazine*, Fall 2020, <https://hub.jhu.edu/magazine/2020/fall/securing-smart-homes/>.

⁴³ Center for Real Estate Technology + Innovation, “2021 Real Estate Tech VC Funding Report.” CRETech, “2019 End Year Report,” 2020, www.crettech.com/reports. Mark Grinis and Michael Beckerman, “Venture Capital Points to the Hottest Concepts in Built-World Tech” (EY and CRETech, 2020), 4, https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/real-estate-hospitality-and-construction/ey-venture-capital-funding-points-to-hottest-concepts-in-built-world-tech.pdf. Also “Q 4 2021 PITCHBOOK-NVCA VENTURE MONITOR” (PitchBook; NVCA; Inspireity, January 14, 2022), https://files.pitchbook.com/website/files/pdf/Q4_2021_PitchBook_NVCA_Venture_Monitor.pdf.

the share of VC funding going to PropTech rose from about 6 percent in 2014 to about 10 percent in 2021.⁴⁴

While the money has gone into a variety of activities, a 2020 study co-authored by Andrew Baum found, not surprisingly, that the largest shares were going into entities focused on big data and big data analytics. Other areas that drew large shares of investments included those related to the internet of things, smart homes, and smart buildings, as well as firms focused on improving work-flow management in the process of designing and constructing buildings. Somewhat smaller shares went into activities related to Building Information Management (BIM) applications, 3D modelling and augmented or virtual reality, and to new approaches to real estate finances and transactions, such as greater use of blockchains and cryptocurrencies.⁴⁵

Several factors seem to be driving this surge. To begin with, the market opportunity is massive. For example, in 2021 the value of the single-family housing market alone was \$36 trillion while the nation's apartment stock was worth another \$5.2 trillion in 2020. Moreover, there was \$11.8 trillion in outstanding mortgage debt for single-family homes (including \$4 trillion in mortgages that were originated in the first quarter of 2021) and \$1.77 trillion in outstanding mortgage debt for multifamily buildings (including about \$360 billion in loans made in 2020).⁴⁶

While digitalization has already changed many key aspects of housing, many technology-focused analysts and investors contend that the pace and scale of digitalization in housing has lagged that in other industries. For example, as Ryan E. Smith and Ivan Rupnik, co-authors of a symposium paper, have noted, "offsite construction, including panellised and modular delivery, is an innovation that has

⁴⁴ Based on total annual VC funding reported in "Q 4 2021 PITCHBOOK-NVC A VENTURE MONITOR," 4.

⁴⁵ Andrew Baum, Andrew Saull, and Fabian Braesemann, "PropTech 2020: The Future of Real Estate" (Oxford Future of Real Estate Initiative, Saïd Business School, University of Oxford, February 2020), 85–87, <https://www.sbs.ox.ac.uk/sites/default/files/2020-02/proptech2020.pdf>; Fabian Braesemann and Andrew Baum, "PropTech: Turning Real Estate Into a Data-Driven Market?" *SSRN Electronic Journal*, 2020, 14–18, <https://doi.org/10.2139/ssrn.3607238>.

⁴⁶ Laurie Goodman et al., "Housing Finance at a Glance," July 2021, 6. "Quick Facts: Investment Returns on Apartments," accessed February 15, 2022, <https://www.nmhc.org/research-insight/quick-facts-figures/quick-facts-investment-returns-on-apartments/>; "America's Rental Housing 2022" (Harvard Joint Center for Housing Studies, January 2022), 28, https://www.jchs.harvard.edu/sites/default/files/reports/files/Harvard_JCHS_Americas_Rental_Housing_2022.pdf; "Total Commercial/Multifamily Lending," accessed February 14, 2022, <https://www.mba.org/news-research-and-resources/research-and-economics/commercial/-multifamily-research/blog/blog-posts/current-blog-posts/total-commercial/multifamily-lending>.

demonstrated performance on individual projects, but has yet to make industry-wide impact.”⁴⁷ And, at least until recently (and in contrast to many other areas), many real estate transactions were done in person and on paper. Taking note of the slow pace of change in these and other areas, Steve Maarbani, a tech investor, contended a few years ago that “driven by the demand for greater efficiencies throughout the sector and enhanced user experiences, new technologies are reimagining every aspect of the way in which real estate is procured, developed, managed, and utilised. The extraordinary pace of innovation in other industries, and the resulting ubiquity of digital technology in everything from ordering a pizza to managing your finances, has heightened consumer expectations of every other aspect of their lives, including their relationship with the built environment.”⁴⁸

Of course, such investments are no guarantee of success. As previously noted, Zillow lost about \$1 billion on its foray into iBuying of homes before it shut that program down in late 2021.⁴⁹ Similarly, despite more than \$3 billion in funding, much of it from well-known investors (such as the SoftBank Group), Katerra, which was making extensive use of digitalization in its efforts to create a more seamless (and less expensive) system for designing and building homes, went bankrupt.⁵⁰ Such failures are to be expected, noted Baum, who in 2017 wrote, “right now, thousands of extremely clever people backed by billions of dollars of often expert investment are working very hard to change the way real estate is traded, used, and operated... No doubt many PropTech firms will fail, and a lot of money will be lost, but there will be some very successful survivors who will in time have a radical impact on what has been a slow-moving, conservative industry.”⁵¹

⁴⁷ Ryan E. Smith and Ivan Rupnik, “Productivity, Innovation and Disruption: A Study of Offsite Construction in the United States,” in *Offsite Production and Manufacturing for Innovative Construction: People, Process and Technology*, by Jack S. Goulding, and Farzad Pour Rahimian (Milton: CRC Press, 2019), 223. See also, Nick Bertram et al., “Modular Construction: From Projects to Products” (McKinsey & Company, June 2019); Carlos Martín and Andrew McCoy, “Building Even Better Homes: Strategies for Promoting Innovation in Home Building” (US Department of Housing and Urban Development, March 2019), <https://www.huduser.gov/portal/sites/default/files/pdf/BuildingEvenBetterHomes.pdf>.

⁴⁸ Steve Maarbani, “Real Estate Technology: Threat or Opportunity?” (KPMG and Real Tech Ventures, May 2017), 1, <https://home.kpmg/au/en/home/insights/2017/05/real-estate-technology-threat-or-opportunity.html>.

⁴⁹ See Will Parker and Konrad Putzier, “What Went Wrong With Zillow? A Real-Estate Algorithm Derailed Its Big Bet,” *Wall Street Journal*, November 17, 2021, sec. Business, <https://www.wsj.com/articles/zillow-offers-real-estate-algorithm-homes-ibuyer-11637159261>; DelPrete, “Zillow Exits iBuying — Five Key Takeaways.”

⁵⁰ Konrad Putzier and Eliot Brown, “How a SoftBank-Backed Construction Startup Burned Through \$3 Billion,” *Wall Street Journal*, June 29, 2021, <https://www.wsj.com/articles/how-a-softbank-backed-construction-startup-burned-through-3-billion-11624959000>.

⁵¹ Baum, “PropTech 3.0.”

A Framework for Assessing Digitalization's Impact on Housing

While it is important to understand how digitalization is changing all aspects of housing, it also is necessary to assess whether these changes are likely to advance (or hinder) efforts to address pressing economic, social, and environmental challenges. Such assessments, in turn, can help identify and assess strategies that public, private, and/or civic entities can use to both increase the likelihood that digitalization will advance efforts to address some key challenges and reduce the likelihood that digitalization will exacerbate key problems.

How Is Digitalization Changing Key Aspects of Housing?

We begin by breaking this question down into five different areas:

- How housing is designed and built
- How investments are made in housing
- How housing is planned, reviewed, and regulated
- How people search for and finance housing
- How housing is used

Digitalization and How Housing Is Designed and Built

The growth of CADD, CAD/CAM, and BIM has dramatically altered the ways that housing is designed and built. Moreover, increased use of AI and machine learning in design and increased use of digital tools in offsite construction could reduce the cost of designing and building new housing and/or improve the quality of those structures. While many of these changes have altered the ways that buildings are constructed, there is widespread consensus that, for the most part, digitalization has been slow to have an impact on the ways that housing, particularly single-family housing is built. However, there are signs that this might be changing.

Digitalization and How Investments Are Made in Housing

Venture capitalists and other investors have poured substantial funds into a variety of entities that have been changing the ways that houses are bought, sold, and used. These changes have fostered the rise of growing number of iBuyers, such as Opendoor, Offerpad, and, until late 2021, Zillow. They also have led to the rise of investors—not only large-scale entities such as Pretium, Blackstone, and Altisource, but also many smaller investors—that use digitalized technologies to find and buy single-family homes and convert them to single-family rentals, which they manage with the help of online platforms. Since these changes have been especially pronounced in growing Sun Belt markets, particularly in historically Black

neighborhoods, they could dramatically affect efforts to expand access to homeownership for people of color, especially efforts to close the historically large Black/white homeownership gap.

New digital tools accessing new types of data may also be reshaping multifamily rental markets. In a 2018 article, Gabriel Morgan Asaftei and three colleagues at McKinsey & Company urged investors in those markets to take advantage of the fact that machine learning and other tools make it much easier for them to incorporate potentially powerful nontraditional variables—such as number of permits to build swimming pools, change in the number of coffee shops, and tone of Yelp reviews for nearby businesses—into their work. “This information,” they noted, “is not traditionally considered real estate data, but stitching such data points together can more accurately predict hyperlocal areas with outsized potential for price appreciation.”⁵² In practice, such investors typically upgrade buildings and then substantially increase rents, which, in turn, reduces the supply of moderately priced housing.

Digitalization and How Housing is Planned, Reviewed, and Regulated

Those who favor or oppose new development or changes to land-use regulations can use mapping tools and other programs that can analyze development patterns, simulate changes in zoning and land-use regulations, and develop more detailed plans. They also can use social media platforms to disseminate these analyses to the broader community and, in doing so, to foster broader civic discussions about plans and proposals. Digitalization also could advance regulatory efforts to address a variety of key housing goals, such as fair housing. However, there are substantial obstacles to these efforts, including the lack of resources needed to develop and maintain such tools and the related fact that it is much harder to monetize the potential benefits of such tools. This, in turn, raises the specter that rather than advancing equity, digitalization might further advantage those with resources in the process of planning, reviewing, and regulating housing.

Digitalization and How People Search for and Finance Housing

As noted earlier, platforms like Zillow and craigslist have changed the ways that people search for homes to buy or rent. Similarly, the growing use of automated underwriting as well as the rise of online entities like Quicken Loans, Rocket Mortgage and loanDepot have changed the ways that people search for and get mortgages. And, as previously noted, digitalization has long been a part of the secondary mortgage market. Because these shifts reduce face-to-face interactions, they could expand access to housing and

⁵² Asaftei et al., “Getting Ahead of the Market: How Big Data Is Transforming Real Estate.”

mortgages for people of color. On the other hand, if explicit or implicit biases are built into the algorithms—or the ways that AI and machine learning alter those algorithms—digitalization could result in continued and perhaps even expanded discrimination in these areas.

Digitalization and How Housing Is Used

As tools like Alexa, Google Home, and Siri have shown, digitalization is changing the ways that we live in our homes. While many of these changes are mainly related to lifestyles (by making it easier to listen to music, for example), they also have the potential to help address several housing-related challenges, particularly the need to monitor energy use in—and GHG emissions from—existing residential units, as well as the need to help the growing number of older Americans safely age in place. In both areas, the challenge is not only to advance key goals but also to ensure that efforts are carried out in ways that ensure that the benefits are equitably distributed, particularly if they involve public subsidies.

Could These Changes Help Address Key Challenges?

While these changes are dramatic and notable, we are particularly interested in whether they are likely to help address (or exacerbate) housing-related challenges, particularly:

- Affordability
- Segregation and discrimination
- Gentrification and displacement
- Resiliency and climate change
- Changing demographics
- Participation and decision-making

How Might Digitalization Affect Affordability?

Could the changes—particularly the way housing units are designed and built but also how they are reviewed and approved—reduce time and money needed to develop new housing and, in doing so, make housing more affordable for millions of cost-burdened households, such as the approximately 20 million renters who pay more than 30 percent of their income for housing (including more than 10 million paying more than 50 percent)?⁵³ Could better analyses of and communication about proposed development speed up the approval process and, in doing so, reduce the time and money needed to develop new housing? Or could some changes, like the growing number of institutional investors buying

⁵³ “America’s Rental Housing 2022,” 3–4.

single-family homes or the ways that digitalization might expand access to the planning process exacerbate affordability problems?

How Might Digitalization Affect Segregation and Discrimination

Can the growing use of AI and machine learning—particularly how people search for housing, obtain mortgages, and are screened by landlords—help eliminate the explicit and implicit biases that can make it harder for people of color, lower-income households, or other marginalized groups to have access to affordable, high-quality housing in vibrant communities? Or are these changes likely to enhance existing dynamics and, in doing so, continue or even worsen these challenges?

How Might Digitalization Affect Gentrification and Displacement?

Could the increased availability of data and its increased use by civic and community groups make it possible to identify and respond to changes that could lead to gentrification and displacement? Or, is it more likely that the changes, which help developers and investors identify neighborhoods in transition, are likely to increase the pace and/or nature of racial, ethnic, and economic inequity in changing neighborhoods?

How Might Digitalization Affect Resiliency and Climate Change?

Are the changes—particularly how housing is built, used, managed, and renovated—furthering efforts to address significant environmental challenges, most notably reducing GHG emissions from residential units and/or making housing more resilient in the face of major natural disasters, which have been increasing in scope and scale? If so, will investments needed to achieve these reductions be made in equitable ways?

How Might Digitalization Help People Age in Place?

Are the changes—particularly how housing is designed, used, and managed—helping to address the changing nature of American households, especially the growing number of older Americans who want to age in place in safe and healthy ways? As above, will such changes occur in equitable ways and in conjunction with other needed improvements to older Americans' homes?

How Might Digitalization Affect Public Participation and Decision-Making

Can digital platforms and open access tools help ensure a broader and more representative set of views in public processes for developing housing-related plans, policies, and regulations? Or are such tools likely to continue or exacerbate the factors that can sometimes favor particular interests such as

“growth machines” that can sometimes overwhelm local concerns in many urban locales and homeowners who frequently limit development in suburban ones?

How Might We Foster More Beneficial Outcomes?

While digitalization’s impacts on housing are still unfolding, they clearly are far enough along that it is possible not only to identify the impacts of key changes but also to think broadly about promising strategies that might advance key public goals and/or to alleviate potential impacts that would exacerbate key challenges. While much of this work will have to be done by the public sector, the private, nonprofit, and civic sectors will also play key roles. The public sector, moreover, can spur those efforts by incentivizing and encouraging desired activities and restricting or penalizing actions likely to exacerbate pressing problems.

Public-Sector Responses

In general, the public sector’s efforts will involve one or more of the following broad approaches:

- Developing regulatory strategies
- Making direct public investments
- Providing financial incentives and disincentives for private-sector entities
- Facilitating the flow of information and data

Regulatory Strategies

Regulatory approaches are particularly important ways to limit certain activities. However, they also can be used to encourage desired actions and to ensure that a variety of key actors all have access to important information. Key regulatory approaches include those that seek to constrain certain behaviors (such as banning discrimination), measure and assess outcomes (such as using disparate impact tests to assess lending decisions), mandating the disclosure of information (such as requirements to provide more information on ownership), or establishing standards and guidelines (such as developing building codes focused on energy efficiency or creating requirements for public processes).

Notably, in early February 2022, US Senators Ron Wyden (D-OR) and Cory Booker (D-NJ), along with Representative Yvette Clarke (D-NY), introduced the Algorithmic Accountability Act of 2022, which they described as “a landmark bill to bring new transparency and oversight of software, algorithms and other automated systems that are used to make critical decisions about nearly every aspect of Americans’ lives.” According to Wyden: “If someone decides not to rent you a house because of the color of your skin, that’s flat-out illegal discrimination. Using a flawed algorithm or software that results

in discrimination and bias is just as bad... Transparency and accountability are essential to give consumers choice and provide policymakers with the information needed to set the rules of the road for critical decision systems.”⁵⁴

Making Direct Investments

The public sector, of course, can spur desired outcomes by investing public resources. For example, the Federal Housing Administration could lead the development of improved mortgage underwriting tools. Similarly, public programs could help fund renovations that would reduce emissions from existing homes, particularly those occupied by households of limited means, or help fund modifications and technologies that would allow older Americans, particularly those of limited means, to age in place. These efforts can involve not only large-scale programs but supporting and disseminating pilot programs and research, which can be effective ways to explore new approaches and spur the development and dissemination of new technologies and approaches.

Providing Financial Incentives and Disincentives

The public sector also can encourage desired behaviors via a wide variety of financial incentives and disincentives. Such approaches can be an effective way to encourage public goals, particularly public goals that require action by a host of disparate private actors. However, such efforts also can be politically and legally challenging. These approaches include using tax credits or tax breaks to incentivize private investment in desirable activities (such as energy efficiency or affordable housing), using taxes and fees to discourage certain activities (such as taxing short-term rentals or penalizing the conversion of single-family homes to rental units), or requiring private investments (such as requiring the use of heat pumps or convection cookware in new residential buildings).

Collecting and Disseminating Information

Finally, the public sector can sometimes help spur private actions by collecting and disseminating information about promising approaches and strategies and by making that information available in ways that make it easier for users and advocates to understand and assess key trends. Understanding the scope of institutional investment in single-family homes, for example, might be greatly facilitated by

⁵⁴ “Wyden, Booker and Clarke Introduce Algorithmic Accountability Act of 2022 To Require New Transparency And Accountability For Automated Decision Systems | U.S. Senator Ron Wyden of Oregon,” accessed February 4, 2022, <https://www.wyden.senate.gov/news/press-releases/wyden-booker-and-clarke-introduce-algorithmic-accountability-act-of-2022-to-require-new-transparency-and-accountability-for-automated-decision-systems>.

federal, state, or local laws and regulations, such as rental registries, requiring that LLCs and other entities disclose information about a property's true owners.

The Private Sector's Potential

While the bulk of the responses to digitalized housing's impacts will, of necessity, come from the public sector, the private sector can also play a key role, particularly in situations where the opportunity to seek profits aligns with public goals. Government-supported enterprises, such as Fannie Mae and Freddie Mac, could (and likely will) play significant roles in efforts to ensure that increased use of machine learning in the mortgage underwriting process advances equity goals. Another promising area appears to be efforts to reduce energy uses from—and even to decarbonize—residential real estate. Several environmental entities have been promoting this possibility for several years. RMI, a leading advocate of using mortgage financing to fund energy improvements in homes, for example, has noted that “innovations in housing data analysis, mortgage processing and automation... can facilitate” the growth of the market for such financing.⁵⁵ Another study, produced by a coalition of environmental groups, contended that digitalization can provide “cost-effective ways to optimise existing energy infrastructure and operations through the utilisation of data and control technologies.” This, in turn, has “paved the way for the creation of new business models that provide better access for consumers and other market participants to fundamentally alter how electricity markets will work.”⁵⁶

Recent years have seen growing interest by investors as well. For example, Fifth Wall, a leading investor in PropTech, announced in September 2020 that it planned to invest at least \$200 million in climate tech-related businesses. “Decarbonizing our modern world is the right thing to do and a personal mission of mine,” explained Greg Smithies, the Fifth Wall partner heading that effort. “In addition to the ethical, normative arguments, I believe it’s also smart business... I see an enormous

⁵⁵ Rita Ballesteros, David Heslam, and Greg Hopkins, “Build Back Better Homes” (Boulder: RMI, March 2021), 6, <https://rmi.org/insight/build-back-better-homes/>. See also Molly Webb et al., “Urban Energy and the Climate Emergency: Achieving Decarbonisation Via Decentralisation and Digitalisation” (London and Washington, DC: Coalition for Urban Transitions, 2020), https://coalitionforurbantransitions.org/wp-content/uploads/2020/03/Urban_Energy_and_the_Climate_Emergency_web_FINAL.pdf.

⁵⁶ Webb et al., “Urban Energy and the Climate Emergency: Achieving Decarbonisation Via Decentralisation and Digitalisation,” 13.

potential upside for an up-and-coming batch of new entrepreneurs and companies—both in terms of returns, but also to help solve arguably the most pressing challenge of our generation.”⁵⁷

Moreover, such investment opportunities are likely to increase with the passage of the Inflation Reduction Act, which not only will spur more investment in renewable energy and a more decentralized energy grid, but will lead “the entire venture ecosystem to pile into” funding “smart, connected, cheap infrastructure” such as smart electric panels, software for everything from new home devices to the revamped electric grid, and other nascent technologies, predicts Abe Yokell, managing partner at Congruent Ventures, a VC firm focused on companies addressing sustainability challenges.⁵⁸

Using Data to Advance Civic Agendas

Similarly, a variety of community groups and civic entities concerned with housing-related issues have used the fact that digitalization makes it much easier (and less expensive) to generate new forms of data and access existing data, and to analyze, display, and disseminate the new and existing data in powerful and compelling ways. As Desiree Fields, who wrote a paper for the symposium, has noted, “rather than embracing a dystopian technological determinism that forecloses progressive digital transformations of housing, we must look to movements that are using platforms and other tools of Tech Boom 2.0 to support long-standing struggles for housing justice.” Examples of these activities, she notes, include “the Housing Data Coalition, which uses New York City public data to create tools such as ‘Who Owns What’ to demystify property ownership; “Justfix.nyc” to support tenant rights; and the Anti-Eviction Mapping Project’s digital storytelling” initiative done with “community partners in San Francisco, Los Angeles, and New York.”⁵⁹ Digitalization also has helped efforts to mobilize support for key changes in housing-related policies. For example, Desegregate Connecticut, a group founded by Sara Bronin, who was a commentator at the symposium, created and has used a powerful online “Connecticut Zoning Atlas,” which shows “how all 2,620 zoning districts and 2 subdivision districts in Connecticut treat housing.” The

⁵⁷ Greg Smithies, “Why I Believe Fifth Wall’s Consortium Might Be Key to Solving One of the World’s Biggest Problems,” *Fifth Wall INSIGHTS* (blog), December 15, 2020, <https://medium.com/fifth-wall-insights/why-i-believe-fifth-walls-consortium-might-be-key-to-solving-one-of-the-world-s-biggest-problems-937d2603c65f>.

⁵⁸ James Thorne, “Here’s What Climate Tech Investors Think of the Inflation Reduction Act | PitchBook,” News and Analysis driven by the Pitchbook Platform, August 5, 2022, <https://pitchbook.com/news/articles/climate-tech-inflation-reduction-act>.

⁵⁹ Desiree Fields, “The Politics of Digital Transformations of Housing,” *Planning Theory & Practice* 20, no. 4 (August 8, 2019): 575–603, <https://doi.org/10.1080/14649357.2019.1651997>.

group uses the tool in its efforts to modify the state’s housing laws, including a successful 2021 effort to reform state laws governing accessory dwelling units (ADUs).⁶⁰

An Overview of Papers Commissioned for the Symposium

To better understand the many ways that digitalization is changing (and could change) all aspects of housing and potential responses to those changes, the Joint Center for Housing Studies commissioned eleven papers by leading experts from a variety of fields familiar with key aspects of housing. The papers were presented in separate panels focused on:

- How homes are designed and built
- How investments are made in housing
- How people find and finance housing
- How houses are used (with a focus on energy efficiency and aging in place)
- How housing is planned, reviewed, and regulated

Panel 1: Digitalization, Design, and Construction

The first panel featured two papers focusing on whether and how digitalization might change the ways that housing is designed and built, particularly whether these changes might reduce the cost of producing that housing and/or improve its design. In one paper, José Luis García del Castillo y López explores whether AI and machine learning spur dramatic changes in the design process, which, as previously noted, already has been greatly changed by CAD and related changes. He contends that while AI and ML can make it faster and cheaper to carry out a variety of discrete tasks that are part of the architectural process (such exploring potential floorplate configurations, estimating costs and energy usage, or generating detailed drawings and plans), such changes are not likely to greatly affect the design of large, generally unique office, civic, or government buildings. However, because housing designs may be more replicable, AI and machine learning could speed up the design and construction of new residences. For that reason, he suggests, AI may become part of already ubiquitous CAD tools, which means that concerted public sector action may not be needed to spur its use in housing design.

The second paper, co-authored by Ivan Rupnik, Ryan E. Smith, and Tyler Schmetterer, examines whether and how strategic approaches to digitalization might help spur long-discussed but still nascent efforts to make greater use of offsite construction approaches, such as modular construction, which

⁶⁰Desegregate Connecticut, “CONNECTICUT ZONING ATLAS,” accessed February 16, 2022, <https://www.desegregatect.org/atlas>.

many believe have the potential to provide better and less expensive housing. They conclude that while digitalization can help spur these improvements, this will only happen if it is done in conjunction with an overall shift to both “modularization” (the process of dividing a product into a system of interchangeable modules) and “product platforms” (systems that use the modules to create products that take advantage of the economies of scale associated with standardization but also are flexible enough to respond to customers’ needs and preferences).⁶¹ They go on to suggest that these changes could be spurred by publicly supported pilot programs and collaborative efforts to develop some uniform standards for the offsite construction industry.

Panel 2: Digitalization and Investments in Housing

The second panel focused on the many ways that digitalization is changing the nature of housing investment, with a focus on how those changes might affect affordability and access, particularly for historically disenfranchised communities. One paper, by Mike DelPrete, explores the nature and impact of the waves of VC investments in entities that over the last 15 years have been changing the ways that housing is bought and sold. He notes that even though entities like OpenDoor and Compass have attracted over \$2B in venture capital funding in recent years and greatly increased the volume of business done through their platforms, both are still losing money (as was Zillow before it exited the iBuying business). As a result, he reports, key entities are increasingly focused on having tighter (and more lucrative) connections with brokers, lenders, and other service providers. While noting this is potentially profitable for the firms, he cautions that if these firms come to dominate the market (as is often the case with digitalized platforms) this strategy may primarily benefit the dominant firms, not consumers.

The second paper, by Desiree Fields, focuses on the rise of the iBuyers, large institutional investors, and others using platforms to invest in and then manage single-family rentals, often in communities that are home to many people of color. The flood of funding for such ventures and the growth of technologies that help investors find and manage such properties, she contends, have created a powerful new class of real estate investors who are contributing to growing inequality—not only by making it harder for people to become first-time homebuyers but also by charging high rents for their

⁶¹ This discussion (and their overview of these concepts) both draw on Tobias Martin, “All You Need to Know About Modularization,” MODULAR Management, accessed September 8, 2022, <https://www.modularmanagement.com/blog/all-you-need-to-know-about-modularization>.

new single-family rentals, aggressively penalizing tenants who are in arrears, and ignoring or delaying responses to maintenance requests.

Panel 3: Digitalization, Housing Searches, and Housing Finance

The third panel turned to the ways that digitalization has already dramatically changed the ways that individuals search for homes and secure mortgages to become homeowners, with a focus on whether these changes are helping—or could help—address equity-related concerns. In one paper, Geoff Boeing, Julia Harten, and Rocio Sanchez-Moyano note that by diminishing the power of traditional market gatekeepers such as real estate agents, rental brokers, and property managers, digitalization might reduce discriminatory practices such as racial discrimination and racial steering. However, using careful analyses of online rental listings, they find that this is not the case. For example, they report that online rental platforms' listings for units in Black or Latino neighborhoods had less information about both the unit and neighborhood amenities than listings in otherwise equivalent white neighborhoods. They also note that an increased use of online communications in all aspects of the search process provides a host of data points that make it easier for landlords, agents, and sellers to discriminate among potential buyers and tenants. Policymakers, they suggest, could address these problems by making better and more extensive use of data to better understand and respond to market conditions and by working with or regulating entities that provide online information.

In the second paper, Vanessa G. Perry and Kirsten Martin examine whether digitalization might help address longstanding racial and ethnic disparities in the mortgage approval process, with a particular focus on four key changes: digitalized banking and FinTech, digital marketing, the inclusion of non-traditional “big data” in credit scoring algorithms, and the use of AI and machine learning in automated property valuation and underwriting models. They conclude that while many current digitalized tools still incorporate historic biases, there are significant opportunities to use digitalization to eliminate and remove these barriers in the underwriting process. This could be done, they assert, via more strategic and vigorous regulatory approaches (which would use both new and existing statutory authority) and new approaches to data analysis that assess whether mortgage applicants are being treated fairly and equitably.

Panel 4: Digitalization, Energy Efficiency, and Aging in Place

The fourth panel focused on how digitalization might support two potentially critical changes in the ways homes are used: making homes more energy efficient and making it possible for the growing number of older Americans to safely age in place. In one paper, Carlos Martín notes that digitalization

enables a host of individual and network-related technologies that could reduce energy consumption in the residential sector, which accounts for about a quarter of all GHG emissions in the United States. However, he cautions that efforts to achieve these reductions cannot overlook several key issues, including whether less affluent households can access needed technologies, addressing important privacy concerns about the data generated by the new devices, and recognizing the many obstacles to getting individuals to make full use of the potentially powerful technological tools. Overcoming these obstacles, he notes, will require coordinated actions by public, private, and civic actors and likely will entail a combination of both publicly funded initiatives (such as programs that will help lower-income households make desired investments) as well as federal and state regulations related to a host of issues including utility rates, spending on demand-side programs by private utilities, and the collection and use of data about individual users.

In a second paper, Jennifer Molinsky, Samara Scheckler, and Bailey Hu note that digital technologies focused on health maintenance, management, and care might allow older adults to safely remain in their own homes longer than would otherwise be the case. However, they caution that such technologies cannot address a host of other important challenges for those who want to stay in their homes, such as housing that is physically inadequate, does not meet accessibility needs, or is unaffordable. Addressing these issues, they note, will require not only additional public funds but also updated regulatory approaches to home healthcare that, until recently, generally have not taken account of key housing-related factors such as the physical condition of the home environment, affordability challenges, cultural sentiments, and legal precedents about domestic privacy. Moreover, they note, these efforts also will require better coordination among the many public, private, and nonprofit entities involved with both health and housing.

Panel 5: Digitalization, Planning, and Regulation

The final panel featured three papers focused on whether and how digitalization might improve the way that housing is planned, reviewed, and regulated. In one paper, Paul Waddell and Arezoo Besharati draw on work they have done in Canada to argue that digitalization of land use data and market analyses makes it possible to create data-driven platforms that can better assess how proposed changes in zoning and other land-use policies might impact real estate markets, including whether they might make housing more affordable. They contend that while that the technology needed for such approaches already exists, the challenge is having the political will to deploy them.

In a second paper, on how big data can be used to increase equity in urban development, Justin Koller, Niko McGlashan, and Sarah Williams note that from the development of Home Owners Loan Corporation (HOLC) maps in the 1930s to more recent restrictive zoning codes, data has often been used to reinforce inequality. However, they add, a variety of initiatives from around the country show that it also can be used strategically to expose inequity and encourage dialogue and debate—approaches that can make developers and cities more accountable and make the development processes more inclusive. Such efforts, they note, generally have used data from both existing sources and from new sources, some developed by public entities and some by research organizations. They also note that while such efforts generally have been carried out by public and/or civic entities, a growing number of private real estate developers trying to build community support for their proposed projects are interested in developing and using metrics that can help them demonstrate that their projects are responding to equity-related concerns.

In the third paper, Nestor Davidson focuses on whether and how digitalization might help efforts to achieve fair housing goals. While acknowledging that many housing advocates have raised significant concerns about algorithmic biases, privacy, and growing power disparities, he contends that new forms of data and data analytics have the potential to advance fair housing goals. These tools, he argues, could provide data that would support litigation and help policymakers design better policies. Achieving these goals, he noted, would require significant efforts to identify, collect, and analyze data. In addition, he cautions, deployment of these approaches must be done strategically and carefully as such efforts are likely to face significant legal challenges and continued judicial skepticism about race-conscious policymaking.

Moving Forward

Taken as a whole, the eleven papers make it clear that digitalization has already impacted many key aspects of housing, notably in the ways that investments are made, how people search for housing, and how they obtain financing. However, these papers also indicate that while significant change has occurred in some parts of the housing system, it has been slower to come to other areas, such as modular and other forms of off-site construction, the regulation and review of housing, and in effectively using technology to reduce energy consumption and make it easier for people to age in place.

Moreover, the papers make it clear that while digitalization has advanced (or could well advance) efforts to address some pressing issues, it may also be exacerbating some of those challenges, such as the ways that the recent entry of institutional investors may have contributed to growing

affordability problems or continued problems with bias in the ways that people find and finance housing. Given the differing impacts, it is not surprising that authors tended to emphasize significantly different approaches to harnessing the power of digitalization to help address key challenges and minimizing its potentially negative impacts. In general, regulatory tools were the preferred approach for dealing with potentially adverse impacts while a combination of regulation, investment, incentives, and collaborative approaches were recommended for areas where positive change seemed more likely to occur.

Carrying out these efforts, as many authors noted, will require addressing a host of challenges, including some significant political and legal obstacles. Indeed, recent political controversies at all levels of government as well as major court cases, including several decided by the US Supreme Court, all show that ambitious efforts to address equity concerns (or climate change) are likely to result in heated political debates and important legal challenges. Moreover, it is important for all actors to recognize that as with other significant technological transformations, there are—and will be—lags between when digitalization takes hold in key areas (including housing), when it will have fully transformed socioeconomic structures, and when institutional frameworks are altered to both help ensure that its benefits are widely shared and its negative impacts—including the distributional impacts of digitalization and responses to it—are limited or are addressed.⁶²

Despite these obstacles, we believe it is important to adopt the perspective put forward by Mayer-Schönberger and Ramge, who wrote: “When it comes to the broader social implications of data-driven markets, we abhor the gleeful optimism of the techno-utopias as much as we shun the gloom of the perennial doomsday prophets. Rather than pretending to predict the future, we should prepare ourselves to shape it, readying the right levers and mechanisms so that we can stimulate beneficial strategies and mitigate negative consequences whenever they arise.”⁶³

In addition, we believe it is important to recognize that, as Williams has noted: “data is a medium to construct and convey ideas, just as a collection of words makes a story, or an artist who uses

⁶² This discussion draws from Carlos Delclós, “Housing in the Digital Age: Trends and Implications,” CIDOB, December 2020, http://www.cidob.org/en/publications/publication_series/notes_internacionales/245/housing_in_the_digital_age_trends_and_implications. That piece cites Chris Freeman and Francisco Louçã, *As Time Goes By: From the Industrial Revolutions to the Information Revolution* (Oxford: Oxford University Press, 2002). and Carlota Perez, *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages* (Cheltenham, UK ; Northampton, MA, USA: EElgar Pub, 2002).

⁶³ Mayer-Schönberger and Ramge, *Reinventing Capitalism in the Age of Big Data*, 217.

paint provides an image of the world... Data analytics and the resulting insights communicated through visualizations have done tremendous good in the world, from easing and stopping disease to exposing exploitation and human rights violations. At the same time data analytics and algorithms all too often exclude women, the poor, and ethnic groups. How do we reconcile the potential of data to marginalize people and reinforce racism with its ability to end disease and expose inhuman practices? These two realities remind us that the same data, in the hands of different people, can produce wildly different outcomes for society because how people use data shows their vision of the world. That's what makes our use of data to change the world at once exciting and alarming."⁶⁴

These efforts, we reiterate, should begin with the recognition that digitalization already has spurred significant changes and is likely to spur even more. Moreover, responses to those changes will clearly need to recognize that different changes are likely to have dramatically different impacts. Notably, some digitally-driven changes, such as those related to smart homes, could well reduce GHG emissions and allow more people to age in place. Others, such as the increased use of digital tools by investors, seem likely to exacerbate key challenges like affordability. And for still other changes, the jury is still out. Continued reliance on platforms to find new housing or the increased use of AI and machine learning in mortgage underwriting, for example, have the potential to either enhance access or amplify existing inequalities.

The wide range of potential impacts underscores the need to carefully assess the nature and impact of key digitalization-driven changes in housing. Hopefully, such assessments will help policymakers choose and design appropriate and effective strategies. These approaches, we believe, should not only involve direct government action but also encourage private and civic actions that advance key public goals and, where needed, discourage and limit those activities that might exacerbate key problems. While much work is needed before these measures are put in place, we hope this symposium, which was one of the first comprehensive looks at how digitalization is affecting all aspects of housing, helps lay the groundwork for that work.

⁶⁴ Sarah Williams, *Data Action: Using Data for Public Good* (Cambridge: MIT Press, 2020).

Bibliography

- “America’s Rental Housing 2022.” Harvard Joint Center for Housing Studies, January 2022.
https://www.jchs.harvard.edu/sites/default/files/reports/files/Harvard_JCHS_Americas_Rental_Housing_2022.pdf.
- Asaftei, Gabriel Morgan, Sudeep Doshi, John Means, and Aditya Sanghvi. “Getting Ahead of the Market: How Big Data Is Transforming Real Estate.” McKinsey & Company: Real Estate Insights, October 8, 2018. <https://www.mckinsey.com/industries/real-estate/our-insights/getting-ahead-of-the-market-how-big-data-is-transforming-real-estate>.
- Ballesteros, Rita, David Heslam, and Greg Hopkins. “Build Back Better Homes.” Boulder: RMI, March 2021. <https://rmi.org/insight/build-back-better-homes/>.
- Barns, Sarah. *Platform Urbanism: Negotiating Platform Ecosystems in Connected Cities*. Geographies of Media. Singapore: Springer Singapore, 2020. <https://doi.org/10.1007/978-981-32-9725-8>.
- . “We Are All Platform Urbanists Now.” Accessed January 14, 2022.
<https://www.mediapolisjournal.com/2018/10/we-are-all-platform-urbanists-now/>.
- Baum, Andrew E. “PropTech 3.0: The Future of Real Estate.” Oxford: Oxford Future of Real Estate Initiative, Saïd Business School, University of Oxford, April 2017.
<https://www.semanticscholar.org/paper/PropTech-3.0%3A-the-future-of-real-estate-Baum/9837e5857a2f2f9f8d145d72158ae34ed9b6eaa4>.
- Baum, Andrew, Andrew Saull, and Fabian Braesemann. “PropTech 2020: The Future of Real Estate.” Oxford Future of Real Estate Initiative, Saïd Business School, University of Oxford, February 2020. <https://www.sbs.ox.ac.uk/sites/default/files/2020-02/proptech2020.pdf>.
- Bertram, Nick, Steffen Fuchs, Jan Mischke, Robert Palter, Gernot Strube, and Jonathan Woetzel. “Modular Construction: From Projects to Products.” McKinsey & Company, June 2019.
- Braesemann, Fabian, and Andrew Baum. “PropTech: Turning Real Estate Into a Data-Driven Market?” *SSRN Electronic Journal*, 2020. <https://doi.org/10.2139/ssrn.3607238>.
- Center for Real Estate Technology + Innovation. “2021 Real Estate Tech VC Funding Report.” CRETI. Accessed January 13, 2022. <https://creti.org/2021-real-estate-tech-vc-funding-report>.
- CRETech. “2019 End Year Report,” 2020. www.cretch/reports.
- Delclós, Carlos. “Housing in the Digital Age: Trends and Implications.” CIDOB, December 2020.
http://www.cidob.org/en/publications/publication_series/notes_internacionales/245/housing_in_the_digital_age_trends_and_implications.
- DelPrete, Mike. “2021 Emerging Models in Real Estate Report,” July 2021.
<https://www.mikedp.com/articles/2021/7/5/the-2021-emerging-models-in-real-estate-report>.
- . “Zillow 3.0: Back to Basics,” February 14, 2022.
<https://www.mikedp.com/articles/2022/2/14/zillow-30-back-to-basics>.
- . “Zillow Exits iBuying — Five Key Takeaways.” Accessed February 13, 2022.
<https://www.mikedp.com/articles/2021/11/3/zillow-exits-ibuying-five-key-takeaways>.
- Desegregate Connecticut. “CONNECTICUT ZONING ATLAS.” Accessed February 16, 2022.
<https://www.desegregatect.org/atlas>.
- Donovan, Doug. “Securing Smart Homes.” *Johns Hopkins Magazine*, Fall 2020.
<https://hub.jhu.edu/magazine/2020/fall/securing-smart-homes/>.

- Drummond, William J., and Steven P. French. "The Future of GIS in Planning: Converging Technologies and Diverging Interests." *Journal of the American Planning Association* 74, no. 2 (April 24, 2008): 161–74. <https://doi.org/10.1080/01944360801982146>.
- Eubanks, Virginia. *Automating Inequality: How High-Tech Tools Profile, Police and Punish the Poor*. First Edition. New York, NY: St. Martin's Press, 2018.
- Fields, Desiree. "Tech and Finance Firms Buying up Homes Doesn't Bode Well for Everyone Else." *Washington Post*. Accessed February 13, 2022. <https://www.washingtonpost.com/outlook/2022/01/04/corporate-landlords-silicon-valley/>.
- . "The Politics of Digital Transformations of Housing." *Planning Theory & Practice* 20, no. 4 (August 8, 2019): 575–603. <https://doi.org/10.1080/14649357.2019.1651997>.
- Freeman, Chris, and Francisco Louçã. *As Time Goes By: From the Industrial Revolutions to the Information Revolution*. Oxford: Oxford University Press, 2002.
- Gawer, Annabelle, and Nick Srnicek. *Online Platforms: Economic and Societal Effects*. LU: European Parliament. Directorate General for Parliamentary Research Services., 2021. <https://data.europa.eu/doi/10.2861/844602>.
- Goodman, Laurie, Janneke Ratcliffe, Jim Parrott, Jun Zhu, DeQuendre Neeley-Bertrand, Karan Kaul, Michael Neal, et al. "Housing Finance at a Glance," July 2021, 36.
- Green, Ben. *The Smart Enough City: Putting Technology in Its Place to Reclaim Our Urban Future*. Ideas Series. Cambridge, Massachusetts: The MIT Press, 2019.
- Grinis, Mark, and Michael Beckerman. "Venture Capital Points to the Hottest Concepts in Built-World Tech." EY and CRETech, 2020. https://assets.ey.com/content/dam/ey-sites/ey-com/en_gl/topics/real-estate-hospitality-and-construction/ey-venture-capital-funding-points-to-hottest-concepts-in-built-world-tech.pdf.
- Hilbert, Martin. "Big Data for Development: A Review of Promises and Challenges." *Development Policy Review* 34, no. 1 (January 2016): 135–74. <https://doi.org/10.1111/dpr.12142>.
- . "The World's Technological Capacity to Store, Communicate, and Compute Information." *MartinHilbert.Net* (blog). Accessed July 9, 2021. <https://www.martinhilbert.net/worldinfocapacity-html/>.
- Hilbert, Martin, and Priscila López. "The World's Technological Capacity to Store, Communicate, and Compute Information." *Science* 332, no. 6025 (April 1, 2011): 60–65. <https://doi.org/10.1126/science.1200970>.
- "Housing's Contribution to Gross Domestic Product - NAHB." Accessed March 8, 2022. <https://www.nahb.org/news-and-economics/housing-economics/housings-economic-impact/housings-contribution-to-gross-domestic-product>.
- MartinHilbert.net. "Information & Communication Quantity." Accessed February 22, 2022. <https://www.martinhilbert.net/information-communication-quantity/>.
- The United States Department of Justice. "Justice Department Secures Groundbreaking Settlement Agreement with Meta Platforms, Formerly Known as Facebook, to Resolve Allegations of Discriminatory Advertising," June 21, 2022. <https://www.justice.gov/opa/pr/justice-department-secures-groundbreaking-settlement-agreement-meta-platforms-formerly-known>.
- Lane, Kin. "Intro to APIs: History of APIs." Postman Blog, October 10, 2019. <https://blog.postman.com/intro-to-apis-history-of-apis/>.

- . “What Is an API and How Does It Work?” Postman Blog, October 5, 2020. <https://blog.postman.com/intro-to-apis-what-is-an-api/>.
- Maarbani, Steve. “Real Estate Technology: Threat or Opportunity?” KPMG and Real Tech Ventures, May 2017. <https://home.kpmg/au/en/home/insights/2017/05/real-estate-technology-threat-or-opportunity.html>.
- Martín, Carlos, and Andrew McCoy. “Building Even Better Homes: Strategies for Promoting Innovation in Home Building.” US Department of Housing and Urban Development, March 2019. <https://www.huduser.gov/portal/sites/default/files/pdf/BuildingEvenBetterHomes.pdf>.
- Martin, Tobias. “All You Need to Know About Modularization.” MODULAR Management. Accessed September 8, 2022. <https://www.modularmanagement.com/blog/all-you-need-to-know-about-modularization>.
- Mayer-Schönberger, Viktor, and Thomas Ramge. *Reinventing Capitalism in the Age of Big Data*. New York: Basic Books, 2018.
- Meek, David. “What Did the MLS Look Like in 1985?” *The Arizona Report™* (blog), May 6, 2019. <https://arizonareport.com/mls-books/>.
- “Monthly Energy Review.” U.S. Energy Information Administration, 2022. <https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf>.
- Moore, Gordon E. “Cramming More Components onto Integrated Circuits.” *Electronics* 38, no. 8 (April 19, 1965): 4.
- National Fair Housing Alliance v. Facebook, Inc., No. No. 18 Civ. 2689 (US District Court, Southern District of New York 2019).
- Neal, Michael, Sarah Stochak, Linna Zhu, and Caitlin Young. “How Automated Valuation Models Can Disproportionately Affect Majority-Black Neighborhoods.” Washington, DC: Urban Institute, December 28, 2020. <https://www.urban.org/research/publication/how-automated-valuation-models-can-disproportionately-affect-majority-black-neighborhoods>.
- Parker, Will, and Konrad Putzier. “What Went Wrong With Zillow? A Real-Estate Algorithm Derailed Its Big Bet.” *Wall Street Journal*, November 17, 2021, sec. Business. <https://www.wsj.com/articles/zillow-offers-real-estate-algorithm-homes-ibuyer-11637159261>.
- Perez, Carlota. *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Cheltenham, UK ; Northampton, MA, USA: EElgar Pub, 2002.
- Porter, Libby. “Planning, Land and Housing in the Digital Data Revolution.” *Planning Theory & Practice* 20, no. 4 (August 8, 2019): 575–603. <https://doi.org/10.1080/14649357.2019.1651997>.
- Putzier, Konrad, and Eliot Brown. “How a SoftBank-Backed Construction Startup Burned Through \$3 Billion.” *Wall Street Journal*, June 29, 2021. <https://www.wsj.com/articles/how-a-softbank-backed-construction-startup-burned-through-3-billion-11624959000>.
- “Q 4 2021 PITCHBOOK-NVCA VENTURE MONITOR.” PitchBook; NVCA; Insperity, January 14, 2022. https://files.pitchbook.com/website/files/pdf/Q4_2021_PitchBook_NVCA_Venture_Monitor.pdf.
- “Quick Facts: Investment Returns on Apartments.” Accessed February 15, 2022. <https://www.nmhc.org/research-insight/quick-facts-figures/quick-facts-investment-returns-on-apartments/>.
- Schwab, Klaus. *The Fourth Industrial Revolution*. First U.S. edition. New York: Crown Business, 2017.

- . “The Fourth Industrial Revolution: What It Means and How to Respond.” World Economic Forum, January 14, 2016. <https://www.weforum.org/agenda/2016/01/the-fourth-industrial-revolution-what-it-means-and-how-to-respond/>.
- Settlement Agreement, United States of America v. Meta Platforms Inc. f/k/a Facebook Inc., No. 1:22-cv-05187 (U.S. District Court Southern District of New York June 21, 2022).
- Shaw, Joe. “Platform Real Estate: Theory and Practice of New Urban Real Estate Markets.” *Urban Geography* 41, no. 8 (September 13, 2020): 1037–64. <https://doi.org/10.1080/02723638.2018.1524653>.
- Smith, Ryan E., and Ivan Rupnik. “Productivity, Innovation and Disruption: A Study of Offsite Construction in the United States.” In *Offsite Production and Manufacturing for Innovative Construction: People, Process and Technology*, by Jack S. Goulding, and Farzad Pour Rahimian. Milton: CRC Press, 2019.
- Smithies, Greg. “Why I Believe Fifth Wall’s Consortium Might Be Key to Solving One of the World’s Biggest Problems.” *Fifth Wall INSIGHTS* (blog), December 15, 2020. <https://medium.com/fifth-wall-insights/why-i-believe-fifth-walls-consortium-might-be-key-to-solving-one-of-the-world-s-biggest-problems-937d2603c65f>.
- Srnicek, Nick. *Platform Capitalism*. Theory Redux. Cambridge, UK ; Malden, MA: Polity, 2017.
- Straka, John W. “A Shift in the Mortgage Landscape: The 1990s Move to Automated Credit Evaluations.” *Journal of Housing Research* 11, no. 2 (2000): 207–32.
- “The Use of Machine Learning for Credit Underwriting: Market & Data Science Context.” FinRegLab, September 2021. <https://finreglab.org/ai-machine-learning/explainability-and-fairness-of-machine-learning-in-credit-underwriting/the-use-of-ml-for-credit-underwriting-market-data-science-context/>.
- Thorne, James. “Here’s What Climate Tech Investors Think of the Inflation Reduction Act | PitchBook.” News and Analysis driven by the Pitchbook Platform, August 5, 2022. <https://pitchbook.com/news/articles/climate-tech-inflation-reduction-act>.
- “Total Commercial/Multifamily Lending.” Accessed February 14, 2022. <https://www.mba.org/news-research-and-resources/research-and-economics/commercial/-multifamily-research/blog/blog-posts/current-blog-posts/total-commercial/multifamily-lending>.
- Tweney, Dylan. “April 19, 1965: How Do You Like It? Moore, Moore, Moore.” *Wired*, April 19, 2010. <https://www.wired.com/2010/04/0419moores-law-published/>.
- Walker, Russell. *From Big Data to Big Profits: Success with Data and Analytics*. New York: Oxford University Press, 2015.
- Warnecke, Liza, Jeff Beattie, Cheryl Kolin, and Winifred Lyday. “Geographic Information Technology in Cities and Counties: A Nationwide Assessment.” Chicago: Urban and Regional Information Systems Association, n.d. https://www.urisa.org/clientuploads/directory/Documents/Books%20and%20Quick%20Study/cities_and_counties.PDF.
- Webb, Molly, Andrew Scott, Ipek Gençsü, and Derik Broekhoff. “Urban Energy and the Climate Emergency: Achieving Decarbonisation Via Decentralisation and Digitalisation.” London and Washington, DC: Coalition for Urban Transitions, 2020. https://coalitionforurbantransitions.org/wp-content/uploads/2020/03/Urban_Energy_and_the_Climate_Emergency_web_FINAL.pdf.

Oracle. "What Is the Internet of Things (IoT)?" Accessed September 8, 2022.
<https://www.oracle.com/internet-of-things/what-is-iot/>.

Whoriskey, Peter, Spencer Woodman, and Margot Gibbs. "This Block Used to Be for First-Time Homebuyers. Then Global Investors Bought In." *Washington Post*, December 15, 2021.
<https://www.washingtonpost.com/business/interactive/2021/investors-rental-foreclosure/>.

Williams, Sarah. *Data Action: Using Data for Public Good*. Cambridge: MIT Press, 2020.

"Wyden, Booker and Clarke Introduce Algorithmic Accountability Act of 2022 To Require New Transparency And Accountability For Automated Decision Systems | U.S. Senator Ron Wyden of Oregon." Accessed February 4, 2022. <https://www.wyden.senate.gov/news/press-releases/wyden-booker-and-clarke-introduce-algorithmic-accountability-act-of-2022-to-require-new-transparency-and-accountability-for-automated-decision-systems>.