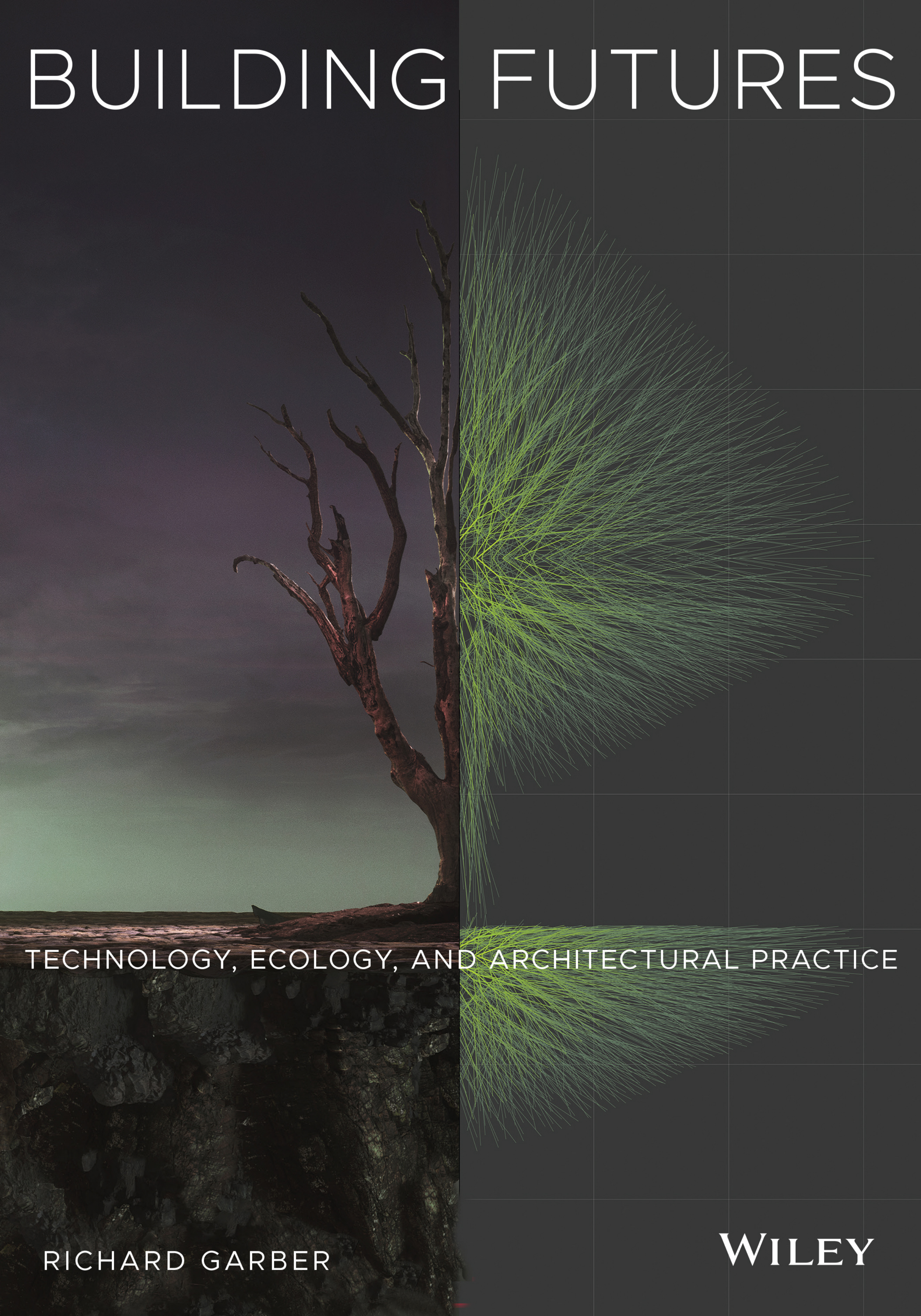
BUILDING FUTURES
TECHNOLOGY, ECOLOGY, AND ARCHITECTURAL PRACTICE
RICHARD GARBER
WILEY

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For Reed, Daryn, and other inheritors of our world.

FOREWORD

ROBERT STUART-SMITH

Architecture is a material response to a diverse array of social, economic, environmental, geopolitical, and discursive conditions. Its means, however, is inherently tied to technological progress arising from both within and outside of the profession. Most notably today, the profession's highly collaborative activities are framed significantly by software that facilitate the conception, communication, and delivery of architectural works. Yet, following creative explorations into digital design in the 1990s and the global adoption of building information modeling (BIM) in practices during the last two decades, the relation of architecture to software is, for many of us, simply a moment in history. Despite its ever-present role in practice, it is seldom a topic of discussion. In particular, BIM, is commonly associated with software programs developed by a handful of companies that has extended 2D and 3D computer-aided design (CAD) into information-rich 3D models. The profession's approach to BIM, however, does not need to remain in this mindset that is focused solely on the partial automation of construction documentation, as there is much more at stake.

The National Institute for Building Standards defines BIM as "a digital representation of physical and functional characteristics of a facility"[1] that "serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onwards."[2] This description is quite similar to that of the *digital twin,* a term coined by Michael Grieves in 2002 but first practiced by NASA during the 1960s. In a 2010 draft report, NASA describes the digital twin as "an integrated multi-physics, multi-scale, probabilistic simulation of a vehicle or system that uses the best available physical models, sensor updates, fleet history, etc., to mirror the life of its flying twin."[3] For NASA, digital twins allow realistic design and problem-solving activities to take place rapidly, with low risk of failure compared to more historically abstract approaches.

This book argues that a forward-looking approach to architectural workflows can also shift BIM toward greater degrees of *digital twin* thinking, and critically and creatively investigates where this could lead.

Today's digital twins can embed and associate data on 3D objects, enabling architects to correlate a vast network of products, manufacturing processes, and material specifications. In other industries, digital twins are already used to assess the workings of several interrelated mechanical parts, or to build entire simulated environments to model scenarios for technologies that must be future-proof (e.g. cell phone reception relative to the placement of radio transmitter towers). In *Building Futures*, Richard suggests we can go much further, drawing our attention to the *Anthropocene* through the lens of Timothy Morton's concept of *hyperobjects*.[4] The world's human-generated climate crisis is presented as one such hyperobject that exceeds both our lifespan and full comprehension, suggesting there must be greater architectural accountability and agency to address it.

The book prompts us to consider simulating events where architecture and architects could mitigate, redirect, or develop contingencies in relation to the environment, flows of material and capital, and other "things" that operate from the immediate, through to almost the geological timescales Manuel Delanda portrays in *A Thousand Years of Nonlinear History*[5] where time is described as a history of flows of geology, disease, and economy, amongst others. This is extended into the broader perspective of *posthumanism,* which Cary Wolfe describes as a "historical moment in which the decentering of the human by its imbrication in technical, medical, informatic, and economic networks is increasingly impossible to ignore."[6] Posthuman approaches to design are advocated for, that recognize there are other species and things that need to be designed for and with, challenging the fact that most architecture is anthropocentric. The book suggests that digital twin simulation and modeling could reframe ideas and the performances of buildings and their respective parts within broader ecological timescales, and calls for more holistic thinking around building design. But is *holistic* the appropriate term? Perhaps not.

The *speculative realist* philosopher, Levi Bryant, advocates for a "flat ontology"[7] (flattened hierarchy), where the human is considered an object, the same as any other object or thing, able to influence and be influenced by any other thing. In Bryant's flat ontology there is no world, container, or meta object that represents completeness or unity. Such a perspective aligns with the book's position, challenging classical notions of architecture's part-to-whole relationships, distancing itself from ideas of composition toward those of assemblage, and questioning whether a building is actually ever a whole or whether its parts are related to, or contribute to the existence of other parts within a flat ontology.

The call to rethink architecture's relation to other objects extends beyond those of object-orientated ontology, championed by Bryant, as well as Graham Harman and Ian Bogost, to the altogether different matter of object-orientated programming.[8] Richard calls into question how architects engage with software, and whether we are constrained by the commercially supported tools we use. Through a series of case studies, the book illustrates the degree to which software is customized by designers from the crafting of bespoke BIM and other workflows by those without programming experience, to scripting customization within 3D modeling software, and beyond, into more serious in-house software development. While software does indeed confine and limit capabilities, the case studies demonstrate that several offices' custom workflows for individual projects have enabled previously infeasible design options to be economically and practically viable within workable design and delivery approaches.

Programming is one of many topics that are used to reframe the scope and agency of the architect, alongside architects' almost direct engagement in digital design-to-production activities such as CNC manufacturing. Increases in productivity and optimizations in project team size and structure resulting from BIM workflows are also touched on. The historically conflicting ideologies of architects, developers, and construction project managers are questioned, suggesting that their disparate interests can align, or at least be resolved as additional criteria within architectural outcomes. If one views architecture as polyvalent and incorporating diverse performative, aesthetic, and constructive criteria, among others, then why not? While BIM is considered the purview of those involved in construction documentation, the book argues that such methods can be extended into feasibility and schematic work, also engaging with real estate development, to further align the interests of diverse parties involved in project initiation and realization. This positive outlook on the increasingly specialized nature of the construction industry is perhaps most notable in discussions on modular construction that is expanding the scope of off-site prefabricated building solutions.

While others see such turnkey design-build companies as a threat to architecture, such as the late Katerra that attempted to fuse architecture and construction within one enterprise, the book takes a different view. Rather than casting the rise of modular construction as a diktat thrust upon architects to build tightly to a predetermined set of specifications, dialogue is demonstrated where architects engage more directly with fabrications during design than has been historically possible, providing more scope for design customization to be jointly developed by the fabricator and designer in partnership, potentially resulting in reduced cost and risk.

Case study projects from several practices are also discussed, where architects have expanded design agency in diverse ways. Given that these developments have been decades in the making, why write this book now? Relative to present and near-future developments, the timeliness of this publication could not be more impactful. First, there is environmental and socioeconomic urgency. Buildings have a substantial environmental footprint, accounting for 39% of energy, 40% of CO_2 emissions, and 40% of raw materials used each year.[9] There is a great need to develop design solutions that reduce this impact and slow climate change. Socioeconomically, many developed and developing economies cannot keep up with demand to adequately house their current populations, not to mention the 9 billion people expected to be alive by 2045 or the estimated 6 billion additional people who will be living in urban populations by 2050.[10] To meet these projections, the building sector needs to become far more productive. Although construction is currently the least productive manufacturing sector, there is hope. A UK government report determined that construction productivity could improve by 60 percent simply by undertaking at least 70 percent of activities off-site prior to construction, where factory-like conditions provide greater degrees of safety and control, and are not disrupted by weather or traffic.[11] Such productivity improvements have the potential to also generate reductions in the cost and time of building, supporting a more affordable architecture.

Government regulation and industry are embracing digital twin technologies at an unprecedented level while emerging technologies are extending the sphere of influence a digital twin can have. Since 2008, there are more things communicating with other things on Earth than people communicating with people. Often referred to as the Internet of Things (IOT), the number of devices or objects connected to the internet that can communicate with people and other objects is estimated to reach 75 billion by 2025.[12] Although typically associated with “smart” appliances such as TVs and fridges that have a computer and internet connection, IOT technologies have given rise to numerous distributed sensor and data-capture devices that track building construction progress or monitor building operations, such as the functioning of MEP systems or structural failure in bridges. Beyond inert IOT objects, there are now commercial companies offering a range of mobile robot systems that can undertake construction site survey mapping,[13] simple building tasks,[14] or be deployed for infrastructural repair tasks.[15] While companies offering these services currently operate in silos, LivingPlanIT is developing an urban operating system (urban OS) that promises to be the glue between everything in the built environment – the ultimate digital twin.[16]

These developments are taking place at the commencement of the Fourth Industrial Revolution (Industry 4.0), which extends Industry 3.0 information and technology systems into autonomous manufacturing and cyber-physical systems. Industry 4.0 promises to enable greater levels of automation and user customization in the physical world through digital technologies. Klaus Schwab, economist and founder of the World Economic Forum, describes Industry 4.0 as having four main physical outcomes in the short term: autonomous vehicles, 3D printing, advanced robotics, and new materials.[17] All of these developments are already influencing building design and construction activities, yet their impact is likely to increase. As they do, BIM digital twin design workflows will be able to more fundamentally connect to these transformations to material and product supply chains, manufacturing, and the delivery of buildings with greater awareness of product life cycles, environmental impact, and the financial and construction risk implications of design decisions. Such digital interconnectivity can support supply chains operating both more globally, and more locally. Industry 4.0 technologies might also enable economical means of distributed manufacturing that could support more locally sourced materials or manufacturing methods.

In the University of Pennsylvania and University College London's Autonomous Manufacturing Lab (AML) we have been developing a multi-robot autonomous manufacturing software framework to support a distributed, adaptive approach to off-site building prefabrication and on-site construction data collection. By connecting heterogeneous teams of robots (mobile ground robots, aerial robots, industrial robot arms, track and gantry systems) to a digital twin model, the manufacture and assembly of a building or building part is able to be decomposed into several discrete operations that can be autonomously selected and executed by robots who work collectively. While this research is relatively nascent in vision and capability, it is being developed in collaboration with industry and the UK government, with significant input from construction companies, engineering firms, and community groups.[18] From this work, it is clear that there is an industry need, and significant gains to be made in human safety, productivity, flexibility, and improved precision, quality assurance, predictability, and risk mitigation. This research offers a glimpse into how valuable digital twin models will become during production, yet they will also have an increasingly significant impact on design.

From a design perspective, Industry 4.0 will facilitate a shift from the dominance of Fordist mass production to a larger amount of post-Fordist mass-customized designs. Fordist production gave rise to modular prefabricated building components that architecturally allowed buildings to be expressed as an assemblage of identical large-scale parts. Although these techniques remain of practical importance, post-Fordist capabilities create space for industrially scalable bespoke production, that lends itself to more variation in the geometric definition of a building's respective parts, their collective expression, and greater design variation between buildings. Designs can become more unique, site-specific, and user-customized, tailored to specific programmatic or climatic conditions. BIM will be the space in which these possibilities are explored, tested, and realized.

Beyond any one specific design capability, Industry 4.0 will provide the architect with increased design flexibility. Some Industry 4.0 technologies, such as additive manufacturing, are relatively design-agnostic, with costs solely related to material volume and build time. Architects can therefore gain aesthetic freedoms providing they engage with the environmental and economic consequences of their aesthetic decisions. It is hoped this will prompt architects to rethink a vast array of relationships and activities around design conception, fabrication, transportation, assembly, building occupation and use, disassembly, reuse, and recycling, among others.

Industry 4.0's reliance on cyber-physical systems also gives rise to a convergence between software and hardware that questions the very nature and modus operandi of architecture itself. Architectural design intent can now be embodied within responsive, adaptive systems, some unseen (such as AI-driven MEP systems) and some aesthetic, user-customizable, or kinetic. Every aspect of a building has the potential to be an IOT part, including a building's own parts. Due to this, an architectural design brief might no longer be so anthropocentric. For instance, the retailer Ocado operates warehouses whose primary occupants are robots. In the journal *Science Robotics*, together with Vijay Pawar and Peter Scully, I argued that architecture itself might soon be thought of as a robotic and autonomous system, with the built environment or buildings themselves comprising an ecology of robot systems.[19]

Governmental, social, and corporate interest toward some form of "metaverse" is also increasing, which, together with web 3.0, blockchain, and cryptocurrency infrastructure, will enable unprecedented connectivity between physical and virtual information, activities, and networks. A BIM digital twin in this context will profoundly impact the way we conceptualize, collaborate, and engage with stakeholders and realize projects.

Dialogue might involve direct user customization or be indirect through feedback from sensory systems. In both cases, a BIM digital twin will operate center stage.

We are at the beginning of a major shift – not only in the means we undertake building design and construction but also in the way we can perceive and initiate architectural agency. It is an exciting time to be in practice, as new connections and agencies can be established to support a more inclusive, ambitious, and impactful architecture. At the same time, a more technological architecture could in some sense become more down-to-earth, extending dialogue to greater degrees with end users, and engaging more directly with many of the issues raised in this book. This book does not champion the status quo of today's BIM approaches, but recasts BIM as a platform in which to further extend our critical and creative thinking – to ask, where do we go from here? The plural nature of the title *Building Futures* implies that there is more than one path forward. In the chapters that follow, possible building futures are explored within speculations on technology, ecology, construction, and practice that are also supported by chapters devoted to a series of high-interest case study projects. These elevate BIM to something beyond its colloquial trivial meaning, pointing toward ideas, concerns, and opportunities that should be at the forefront of every architect, academic, researcher and historian's mind. Curiously, Richard's first chapter commences with a quote from *Tenet* – perhaps one of the most mind-blowing science-fiction films of the decade. As does *Tenet*, the book stitches together events from the recent past in order to influence our future trajectory. *Building Futures* thus really speaks to the one moment that can always change what lies ahead – the here and now.[20]

NOTES

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INTRODUCTION: BUILDING FUTURES

Building information modeling (BIM) has seen widespread use and adoption in the architecture, engineering, and construction (AEC) industry in recent years, with general agreement in both the applicability and use of BIM systems to support aspects of design, construction, and post-occupancy facilities management. Most efforts to enhance both standardization and efficiency have been coordinated by groups such as the US National Institute of Building Sciences (NIBS) and American Society of Civil Engineers (ASCE), which offer publications and events as well as consultation and advocacy in support of these goals. A perusal of information available suggests a forward-looking, if not slightly dated, attitude toward building information modeling, with slogans such as "the future starts with civil engineers" or ". . . buildings of tomorrow" or "what the industry sees today and predicts tomorrow."[1] Given the goal of expanding both the utility and territory of information modeling practices here, it is useful to understand how these tools are regarded by the industry.

Quoting the US National Institute of Building Sciences, which has been cited in some of my earlier work on this subject, building information modeling refers to the "use of the concepts and practices of open and interoperable information exchanges, emerging technologies, new business structures, and influencing the reengineering of processes in ways that dramatically reduce multiple forms of waste in the building industry." This definition, which existed as early as 2008,[2] clearly suggests that building information modeling should be treated as more than a software or set of digital tools but as a series of protocols with goals of achieving a more sustainable basis for the work that architects and our allied collaborators perform in the service of Earth.

Waste in this sense has more generally been measured by efficiency, as in *waste of time* or *waste of money,* than it is with the necessary goal of reducing excess in the form of carbon emissions or construction refuse; and much of the work being focused on now with respect to standardization involves specific relationships between design, the (increasingly) virtual data generated to support the construction of a building and that construction (labor) itself.

These efforts are noble, and by virtue bring architects closer to both the building site and the very craft of building – places and actions from which we have been long since removed by both contract and practice. The rapid advancement of technology has not only created intense competition among contracting firms, but also the methodologies used in building construction – the *means and methods* we as architects have been taught to avoid. Such change is welcomed by many and is slowly being adopted as larger and more complex aspects of the industry, which include material procurement and supply chain positioning against a backdrop of global demand, are exposed. The intensity of these pressures, following a global pandemic and increasing awareness of – and involvement with – nature events precipitated by global effects of climate change, finally allow for a broadening of what precisely building information modeling is, and how we architects and designers access its potentials, given these advancements in both computation as well as an expansion in the scope of architectural process.

Building information modeling as the process of design, via engagement of new digital protocols, has the capacity to both raise specific issues through *design research* and solve specific problems through *applied design*. This idea of exposing issues through a process of research has been a core aspect of the work of the architect and is a practice we should seek to duly expand through the role of both *modeling* and *models*, in the design process, ensuring we are at once not relegated simply as problem solvers, but also imparted with the ability to understand and engage the broad and complex problems of building. An information model is a virtual database that can accept, process, and simulate multiple constraints and inputs, including creative and economic flows of capital, and is the result of a design process. It is the result of creative work and a physical output of design and is therefore representative not only of design intent but also our very agency as architects.

I would like to thank GRO Architects and in particular Mia D'Alessandro, Huajie Ma, Jake Hamilton, Zeina Husayni, and Yifan Shi in the preparation of images for this book.

NOTES

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1

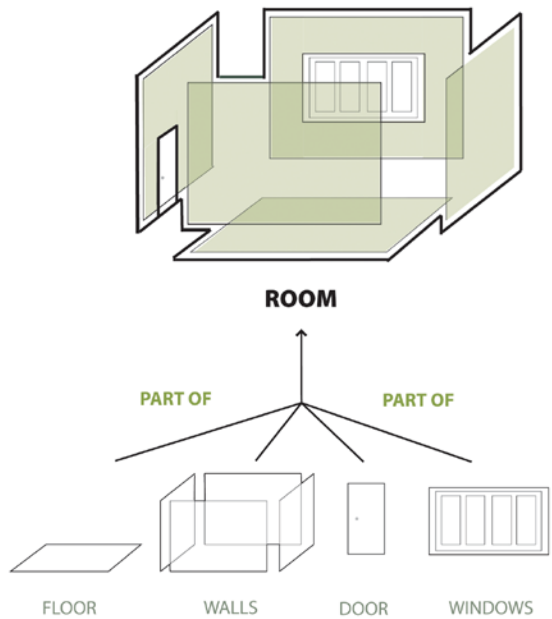
PART 1

1 | ON TECHNOLOGY I

The Protagonist, "He can communicate with the future?"

Priya, "We all do, don't we? Email, credit cards, texts. Anything that goes into the record speaks directly to the future. The question is, can the future speak back?"

— Tenet, 2020



INFORMATION, OBJECTS, AND THE EXPANDED FIELD OF ARCHITECTURAL DESIGN

On a recent, albeit prepandemic, trip to Beijing, a colleague there described an entertaining, if not concerning, story about the use of software in the service of architectural design. Building projects in China are increasingly required to be completed using building information modeling (BIM) software so that a virtual model can be tendered as part of a final drawing submission – a process already broadly adopted in Europe and the United States; however, many Chinese-based firms are still in the process of adopting these technologies and are simply completing building design with traditional two-dimensional CAD systems and providing a three-dimensional model as an afterthought. As such, the model is neither "live" nor "connected" to the drawing set – it is in effect a stagnant set of virtual data.

There has been a steady pressure to adopt BIM platform(s) rooted in a more *efficient* way of working. This has culminated with many architecture firms coming to the schools looking to hire recent graduates who simply "know BIM," as they either have a project whose deliverables require a model, or there is a general sense that other firms have invested in the technology so why shouldn't they. At some level, this is not all bad – many firms have created positions for BIM managers. However, there is a contradiction that we must confront: while most young architectural designers are versed in software, the digital tools utilized to support the architectural design process, they have less experience in building or, more specifically, in how such tools relate to construction. This is a contradiction that has serious implications in the creative use of these tools and how we conceptualize their use in establishing new workflows or processes in the service of design.

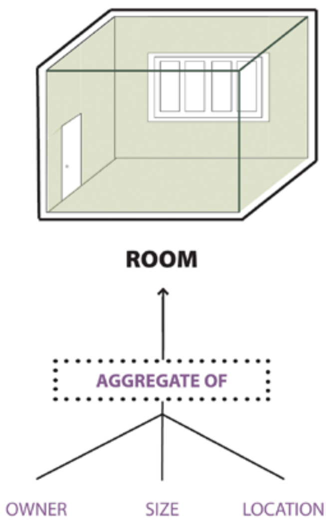


Figure 1.1 Meronyms and Holonyms, 2022: Part-to-whole project relationships as understood through modeling technologies allow better visualization and convey understandings of how things go together. These relationships increasingly anticipate use and post-occupancy scenarios following the construction phase of a building. Interestingly, in object-oriented computing, an architectural example – a room – is used in establishing aggregate taxonomies.[2] The term *meronymic* is used in establishing the relationship between a meronym (part) and holonym (whole). A window is a meronym of a room, which is its holonym.

There seems to be disparate trends within the schema of modeling tools, which continue to become more sophisticated without measurable impact in the building industry, perhaps pointing to a lack of conceptualization of the tools themselves and their use in the service of architectural design. Utilization of these tools directly concerns our agency as architects and our relationship to building, yet also demonstrates an instrumental, if not consumerist, interest in the adoption of a new technology – BIM. Such a position privileges an efficiency of working methods as opposed to the engagement of information models as a new suite of modeling and simulation tools that support novel exploration and creative probing of design problems. Still, it is the "unmatched potential of technical drawing to refer to the material world that make it so extraordinarily effective in the representation of architecture.[1]"

New modeling operations have been continuously refined in both a technical and speculative way through more specific integrations with geometry and process. Equally important in this process has been the relationship between design and abstraction. Though abstraction plays a critical role in design, specific aspects of BIM have sought to reduce abstraction, which is sometimes incorrectly understood as "imprecision." A specific role of the digital twin concept is to minimize abstraction. To better understand this, abstraction as it relates to both preliminary design operations and construction phase services should be more precisely defined. Abstraction is not *vagueness*; in a design sense, it involves the isolation of certain design variables so they can be better understood relationally as they support the interconnectedness of architectural objects and allow the designer to better understand part-to-whole relationships. When understood this way, abstraction becomes an equally important tactic when making more downstream design decisions, where integrated project workflows begin to solely focus on efficiency.

Abstraction at the stage of building actualization can be a powerful operation when utilized within a virtual environment in understanding specific relationships between building components. Whether this is a relationship of a structural member to an architectural feature or a plumbing or gas riser to a wall cavity or mechanical shaft, abstraction in this sense involves isolation within a virtual construct to better understand a relationship between *things*. Such operations are increasingly occurring in virtual or augmented reality environments that allow teams to isolate discrete components to study how they are implemented during, and relate to other objects through, construction.

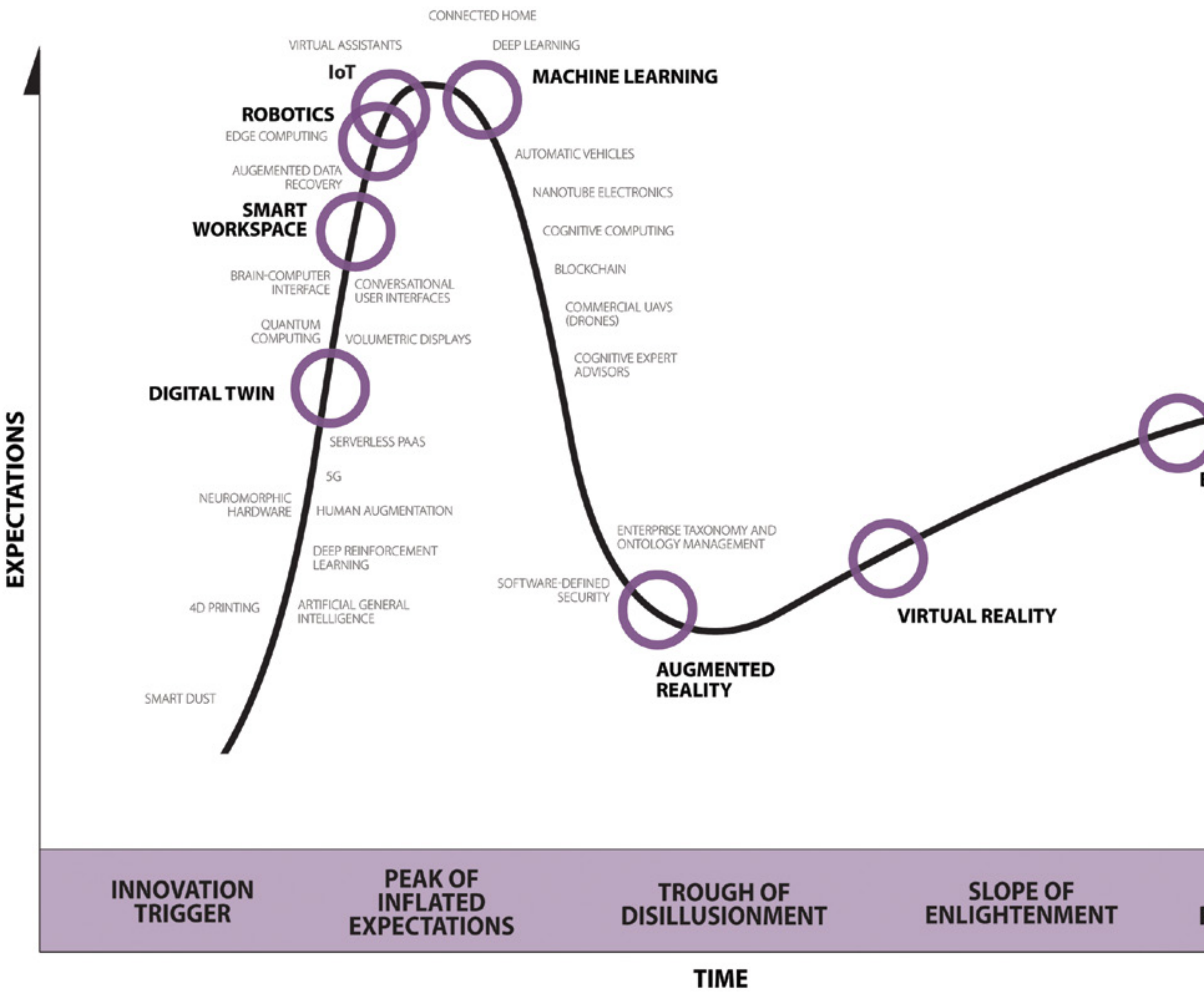


Figure 1.2 Gartner Hype Cycle for Emerging Technologies, after UNStudio, 2017: The Gartner Hype Cycle for Emerging Technologies positions BIM and Virtual Design and Construction as mature, if not technologies that are at their plateau of productivity. Other AI-influenced technologies such as machine learning and smart office environments are "hyped."

PROCESS MODELING AND TECHNOLOGICAL ONTOLOGY

Information modeling as it relates to building is a flexible, and expandable platform, and should not be understood solely as a new technological interface, such as computer-aided drafting (CAD) was in the 1980s and 1990s. While some of the design world is still in a backward-adopting position, that is, it is still transitioning from CAD or simpler design and documentation systems to more robust ones that allow for digital design and virtual construction, others correctly understand it as a projective and flexible set of technologies that allows architects to better understand and inform their intentions with more automated feedback to our work including digital twinning, production automation through robotics, and smart workspaces. These are seen by some as supplanting conventional BIM.