C h a p t e r   1 0

Simulation Research

10.1 INTRODUCTION

Simulation research comes out of a broader human fascination with the replication (*mimesis*, imitation) of real-world objects and settings. Very early in Western ideas, Plato warned of the deceptive nature of copies of reality, while Aristotle valued their therapeutic value (specifically the viewing of theatrical performances). Both these points of view relate to simulation research. Mirroring Plato's concerns, simulation's very goal is to create "copies" of reality. How accurate are the copies? What do copies of real things leave out about those real things?[1] For simulation researchers, these are basic questions. And then there is Aristotle. Aristotle taught that art's very nature (specifically poetry, which includes drama) is to represent how things *could* be, not how things actually are, and viewing enactments of these possibilities can be therapeutic. This is because we can experience emotions stirred by the representations without undergoing the dangers of the real things they represent. Applied to simulation research, this is one of its strengths: we can learn about earthquakes without loss of life; we can learn to fly airplanes without fear of crashing; we can simulate an entire bustling city without the expense of actually building it.

Simulation is a remarkably ubiquitous research design, which can be deployed across a broad range of topics, for purposes that span from highly targeted applications in design projects to theory building. Just as significantly, simulation frequently lends itself to many uses as a tactic within other research strategies, or as a full partner in combined strategies (see Chapter 12).

In particular, the combination of experiment and simulation in sequenced phasing is commonly deployed in environmental technology research (see Chapter 9 for some specific examples). Similarly, within the context of other research designs (for example, correlational or qualitative designs), people's reactions to various settings, simulated by photographs, full-scale mock-ups, and the like, can be effectively investigated. Likewise, simulation can also augment historical research to investigate the technical advances in notable building exemplars over time, as described in an example later in this chapter.

With this overview as a backdrop, we first focus on some of the most recent developments in simulation research enabled by advances in computer technology.

10.2 CURRENT EXAMPLES OF SIMULATION RESEARCH

The dictionary defines *simulation* as "the representation of the behavior or characteristics of one system through the use of another system, especially a computer program designed for the purpose."[2] This definition covers the general meaning of simulation, but it also recognizes the increasing dominance of the computer in this field. In the 10 years since the first edition of this book was released, this has become the case with regard to simulation as an architectural research strategy; computer technology has enormously expanded. "Building information modeling," understood in its generic sense, not only dynamically models buildings spatially and operationally in 3D, it can also model construction management sequences of a building project (called 4D), life-cycle factors projected over longer periods of time, and project costs in real time (called 5D). Here are some examples of how computers have revolutionized simulation studies.

10.2.1 Simulation of Complex Human Factors

Evacuation of Buildings during a Fire. The first edition of this book provided a simple example of computer modeling for evacuation of a building during a fire.[3] Advances in this technology can be seen in recent computer simulations of different evacuation scenarios in the World Trade Center North Tower during the September 11, 2001, attack:[4] What if one stair shaft remained intact above the impact zone in the initial hours after the tower was hit? What if the occupant load was at full capacity (about 25,000 persons); how many would have perished given the actual exiting configurations? What was the impact of firefighters *entering* the building on people trying to evacuate the building? What was the wait time for people exiting from the upper floors? "Five years ago," the authors say, "it would have been considered a challenge to perform an evacuation design analysis for a 110-story building with 25,000 people. With today's sophisticated modeling tools and high-end personal computers this is now possible."[5] For example, the authors found that, for a fully occupied building, all surviving occupants above the 91st floor (topmost floor of impact) could have exited the building prior to its collapse if at least one stair remained intact. Obviously, this calls for strategic dispersal of stairs in future designs. The researchers further postulated from their modeling that, while it is intuitive that higher floors result in longer wait times for exiting, there may come a point when wait times hold steady above a threshold height. This may raise questions as to why we need to build ever-taller buildings. This study is also significant in showing that simulation research is not only useful for projecting future conditions; it can perform analyses of a forensic nature for past events.

10.2.2 Simulation in Earlier Stages of Architectural Design Process

Virtual Reality in Schematic Design and Design Development; Rapid Prototyping. Earlier systems of computer-aided design were more properly called computer-aided drafting: the computer as a sophisticated pencil for producing construction documents. The second generation of computer-aided systems, such as the Revit software, is "smarter" in that the system responds to a change made by the user by updating all other conditions affected by that change. Now computers are beginning to assist design decisions in the earlier stages of schematic design and design development. For example, researchers at the University of Washington studied the use of virtual reality imaging technology in a student architectural studio.[6] Early design ideas were programmed so the spaces could be experienced virtually. Interestingly, one result was a return of interior design as a primary architectural task:

> The use of VR early in the design process forced the detailed development of the interior space as much as the exterior. By having the opportunity to "go inside" the design and see it from within, the designer was forced to solve complex connections and details which would not have been apparent with other media.

The technology brought to light "spatial implications . . . with and without furniture." All of this was not available by conventional means. Limitations still abound. The researchers show that early schematic design is still difficult to adapt to the computer; it is only after initial design concepts have been sketched by hand and programmed into the computer that the virtual modeling becomes helpful in design development. Nevertheless, what is significant here is the blurring of human with computer capacities in the earlier stages of architecture design, with the result that the conventional means of representing architectural design (plan, section, elevation) seems to be increasingly giving way to animation technology allowing for dynamic three-dimensional models. In actual professional practice, the architectural firm Perkins + Will is leading the way in understanding how building information modeling (BIM) simulation can inform each stage of the design process, including conceptual design and schematic design. At these earlier stages, simulation helps to understand climate information, shading scenarios, orientation, and passive strategies.[7]

This leads to another example of simulation in early design thinking: rapid prototyping technology. Michael Speaks has proposed that the rapidity with which this technology allows a designer to produce three-dimensional alternative solutions has blurred the distinction between thinking and doing. The prior order of things, Speaks argues, privileged thinking over doing in that design actions were guided by predetermined theoretical principles held to be true. But if thinking can be expressed almost simultaneously by three-dimensional rapid prototyping, design prototypes can be "tested, redesigned, retested quickly, cheaply, and under conditions that closely approximate reality."[8]

10.2.3 Integration of Simulation Software

UrbanSim, ESRI ArchGIS; Virtual City Template. Because it is the nature of simulation research to provide holistic representations of real-world venues or events, accuracy of representation requires inputting as much data about those venues and events as possible. Here again computers are the ideal platform for simulation research; computers can "simulate the tiny forces binding molecules . . . the support structures of huge skyscrapers . . . the behavior of the economy," and so on.[9] Computerized geographic information systems (GISs) construct models predicting urban growth, transportation networks, and other large-scale built phenomena. These computer models manage extremely complex databases. For example, CityEngine is a 3D modeling software specializing in detailed urban environment simulation, used by urban planners and architects. Supporting industry-standard formats such as ESRI shapefile, 3D models, and AutoCAD DXF files, it enables designers to easily import and export data to create detailed simulation of urban environments. Its interactive design tools facilitate quick editing and modification of urban street layouts and facades. ESRI's Virtual City Template is an example of this technology.[10]

Another example is a program developed at the University of Washington to model urban growth (UrbanSim). This software expanded the scope of traditional two-dimensional GIS modeling, usually covering large scales of spatial area, to fine levels of detail, with integration of three-dimensional modeling capability. The ability of geographic information systems tools to capture, store, and analyze mass data enables projections of urban design scenarios that can dynamically simulate outcomes if given a set of hypothetical inputs.[11] Households, businesses, developers, and governments all make decisions. "By treating urban development as the interaction between market behavior and governmental actions UrbanSim is designed to maximize reality, thereby increasing its utility for assessing the impacts of alternative governmental plans and policies related to land use and transportation."[12]

The notion of "maximizing reality"requires further study. Increasingly powerful computer simulation technology raises a concern over the difference between "reality," understood as everyday real-world contexts and events, and "hyper-reality." This latter term designates computer-generated images and environments that may be "more real" than what we can expect in actuality. And so, while a persistent tactical concern of simulation technology is its ability to accurately represent reality, there now emerges a concern of what we might call overrepresentation. At any rate, one question for powerful programs such as UrbanSim is to what extent they can strike the balance between underrepresenting the outcomes of large interactions of data, versus producing outcomes that are more idealized than real.

BOX 10.1

GeoDesign Suite Tool

We are at a juncture in computer technology where computer-aided design tools are being updated by the next stage, which are simulation tools. This enables computer technology to be more active at earlier stages of design thinking and process. The GeoDesign Suite tool, being developed at the School of Design and Construction at Washington State University, is an example. The GeoDesign Suite works with parametric modeling. The program has a concept function generator, with smart sketching technology, which not only receives the designer's own inputs, but immediately relates it to known images and patterns via Google Goggles.

The research shown (see Figure 10.1) also proposes a more advanced simulation modeling capability, called algorithmic tools. Here, a 3E Dashboard provides calculation gauges for the three significant aspects of sustainable design: equity, efficiency, and environment (the 3E). By providing sophisticated algorithms for each component of the 3E, this tool outputs detailed assessments for different design scenarios in real time, which tremendously enhances the decision-making process. With this simulation technology, designers can quickly adjust their designs for specific goals, making optimal decisions based on real-time feedback from the gauges.

(*Continued*)

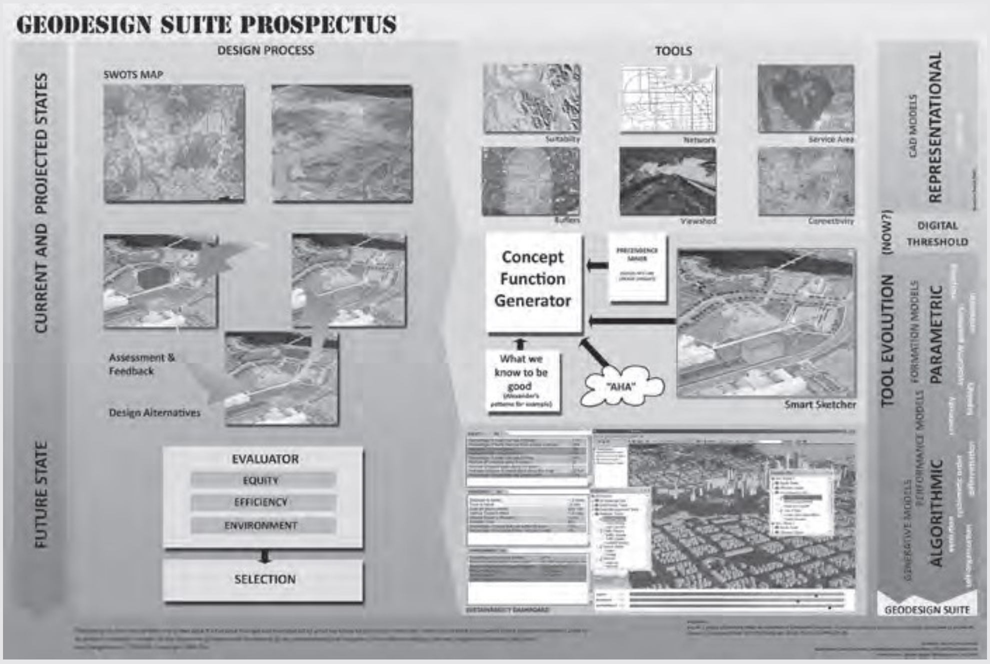

Figure 10.1 Panel featuring the GeoDesign Suite Tool, being developed at Washington State University School of Design and Construction. Courtesy of Brooks, K., A. Joplin, and M. Xu.

10.2.4 Real-Time Simulation

"Sentient Buildings." In the first edition of this book, we noted the trend toward "intelligent buildings." Jong-Jin Kim described a scenario using an "intelligent card":

> [W]hen an employee enters a main entrance lobby using an IC card, the central building administration system sends an elevator to the lobby. As the person proceeds and enters his/her office, the IC card sends instructions to turn on the lights and the air distribution unit. In the evening, IC cards help to determine whether a space is occupied and, if it is unoccupied, the environmental systems are turned off automatically.[13]

This research has of course progressed. Computer programs can tailor a building's mechanical and electrical systems to perform in response to user needs in real time. Patterns of user behavior are recorded by sensors distributed throughout a building. From this data, a computer program then internally simulates alternative scenarios of optimal configurations for energy savings in lighting or thermal levels for real-time occupant loads. In his "Self-Organizing Models for Sentient Buildings," Ardeshir Mahdavi designates four basic components to a sentient building system. First is the *controlled entity*, which can be a single space or spaces networked over an entire building. Second, sensors in the controlled entity (or impact zone) measure a range of inputs such as environmental factors, real-time occupancy loads, outdoor conditions, and the like. A *controller* is the decision-making agent, the computer program that simulates "representations" of possible scenarios. It can then make changes in the controlled entity by means of altering a *control device*.[14] There are now commercial products that can perform simple versions of these functions; the Nest Thermostat is an example.[15] This control device not only records patterns of energy use for easy review of costs, it also learns the behavior of the occupants. For instance, it automatically adjusts temperature settings based on patterns for when occupants leave the home or retire for the night. Godfried Augenbroe outlines an easily envisioned future development for this technology:

> Simulation may be part of an e-business service, such as the web-hosted electronic catalogue of a manufacturer of building components. Each product in the catalogue could be accompanied by a simulation component that allows users to inspect the product's response to user-specified conditions.[16]

With increasing miniaturization, a more radical idea for component simulation is smart cells, working as computerized components within our bodies. Upon inputs such as exposure to infection, these cells can "represent" various scenarios and trigger the most favorable responses within our bodies. An idea such as this underlines the fact that the computer revolution will probably redefine "architecture" as we know it much more than the Industrial Revolution ever did.

10.2.5 Immersive Building Simulation

CAVE. This is technology by which a user can be placed "into" a three-dimensional computer-generated environment, one that responds (ideally) to the user's real-time actions. The term *virtual reality* is often used in this sense. Virtual simulation can be immersive, in which the user experiences complete inclusion in the simulated setting; or augmented, in which a device allows the user to see into some sort of simulated context overlaid on real-world settings. The first edition of this book cited CAVE (Computer Assisted Virtual Environments), to illustrate this technology; a collection of research papers on this technology is still available online.[17] Ali

Malkawi's "Immersive Building Simulation"[18] outlines the progress of this research since that time. Malkawi notes that building simulation of this kind actually lags behind other uses of virtual or augmented reality simulation, such as flight simulator technology or military applications of simulated theater operations. Malkawi notes that this technology is still experimental, and costs are still high. But, again, it is quite easy to envision how totally immersive environments will be part of our lives in the not too distant future. This has implications not only for architecture, but also for medicine, conduct of business, entertainment, travel, and a host of other areas of life.

10.2.6 Modeling Construction Sequences

Building Information Modeling (BIM) enables dynamic simulation of at-one-point scenarios, but more significantly, the behavior of structures under construction over time. For instance, the program models initial concrete pours, but also follows the concrete as it cures; thus, it is able to guide when forms can be removed. The program calculates the loads on the building frame during pouring and during vibration of the concrete (which creates large loads), and calculates the new distributed loads while forms are removed. The BIM program manages basic information, which includes the 3D geometric data of the project; 4D information, which contain resource information, site information, and scheduling and processes data; and structural information (loading conditions, structural profiles, and the like). It generates integrated solutions from these data sources. One outcome is the ability to project (so as to avoid) collisions of machinery on construction sites. The authors claim their work is the first to establish a "4D space-time model" that helps managers "analyze and avoid possible collisions during the whole construction process."[19]

10.3 STRATEGY OF SIMULATION RESEARCH

Here we address the defining characteristics of simulation as a research strategy. Part of this task is to clarify some terms often found in the simulation literature. Because advances in computer technology occur so quickly, it is useful to consider some of these definitions. Following these clarifications, we outline some relationships simulation research has to other research strategies.

10.3.1 Representation versus Simulation

The word *representation* often occurs, with various shades of meaning, in the simulation literature. For our purposes, representation denotes a fixed image that stands for a real object because the image has measurable qualities that describe and depict the real thing. In this sense architectural drawings are representations. Photographs, the medium that much of architectural education has been dependent upon up to now, are also representations under this definition. To-scale three-dimensional architectural models are representations as well. It is only when data from various scenario inputs can be generated from representations that we can say simulation is taking place. This can be achieved with fixed representations.

An example is a study utilizing photographs (slides) and to-scale models of nursing homes. Rather than bringing elderly people to the actual buildings, seniors were shown models and a series of slides of the spaces. It was shown in this case that those experiencing the depicted environments had a better "working knowledge" of the buildings than those who actually visited them. The latter group experienced difficulty finding places out of sequence from their initial site exposure, but the group that was exposed to the fixed photographs and models did not experience similar difficulty (they in fact found places not included in the simulated visit).[20] Because data came out of these interactions with the still images, the research was included in a collection of examples of simulation research.

Computer technology has further blurred the distinction between representation and simulation. For example, the popular software Sketchup, freely downloadable from Google, offers almost infinite views of a building, in plans, sections, aerial views, and the like, after the dimensions have been input. Is this representation or simulation? Most would say it is a representational tool because the many views Sketchup generates are still themselves fixed and operated by the user. It is not until there is a "smart" capacity in a computer modeling program that allows for dynamic interactions yielding measurable data that we can say simulation modeling is taking place. Closer toward simulation is something like sun path scenarios. Autodesk's Revit program projects the sun's position relative to a building at any time and any location. These are fixed representations that nevertheless begin to offer dynamic information. Perhaps the salient point is that advancing computer technology may bring us to a point, as some of the preceding examples suggest, at which an infinite number of fixed representations in sequence achieve simulations of "real-time" behaviors. Because we are in this transitional time, the word *representation* may be used with differing shades of meaning by various commenters in the simulation arena.

10.3.2 What Is a Model?

This is another ubiquitous word used in simulation research. In simulation terms, a *model* is the overall system that simulates the reality being studied. A model can exist in a variety of forms: from a mathematical model comprised of abstract numerical expressions, to laboratory spaces outfitted (for instance) into conference rooms to test lighting,[21] to what architects still most often think about when the word *model* is used, small-scale three-dimensional representations of actual spaces (see Figure 10.2a). In the Netherlands, it was a practice for full-size mock-ups of entire residences to be tested before actual construction proceeded (see Figure 10.2b). The process is able to reveal under research conditions why, on subjective grounds, some people prefer certain environments and not others.[22] (This is another example of a "fixed representation," here a full-sized replica of a residence, yielding data through dynamic interactions with "residents"; therefore, it is simulation).

In a recent book on design research, Sally Augustin and Cindy Coleman discuss how simulation findings can be derived from fixed models. They call it *space simulation,* by which they mean fixed models that can range from "incredibly detailed and realistic" to three-dimensional boxes that roughly approximate a space. One point to take from their observations is that these space simulations ought to be able to "learn" over time: "As users interact with one simulation, it should be

Figure 10.2a A to-scale model of a proposed church interior. One can orient the model to the sun in such a way that would suggest how the actual space might look under the same conditions. But generally, fixed architectural models are representations more than simulations. Courtesy of Professor Matthew Melcher.

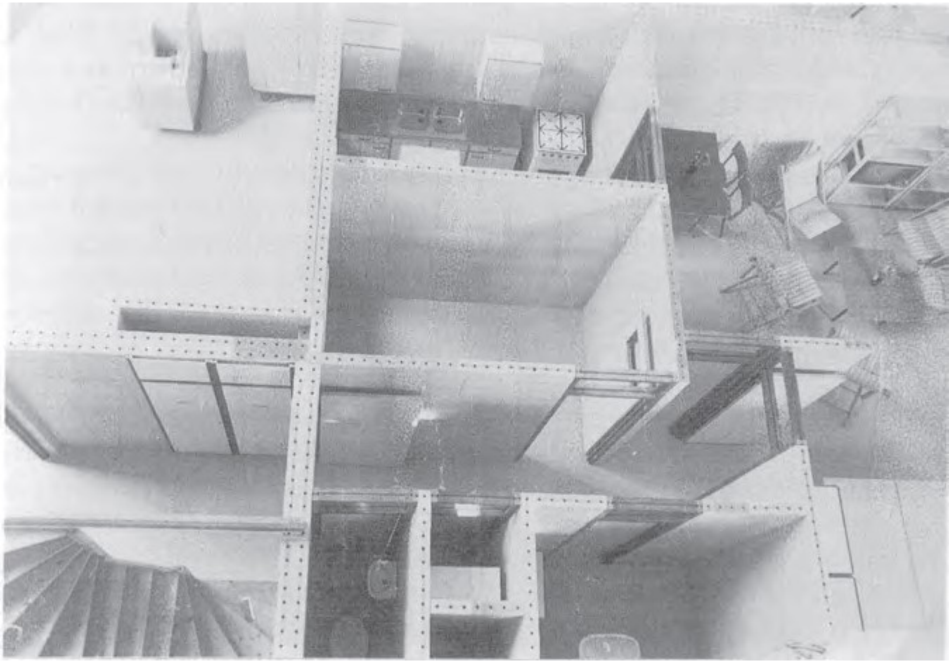

Figure 10.2b Full-size mock-ups of residential spaces in Amsterdam: residents participated in these simulated environments prior to actual construction of the design. Courtesy of Plenum Press. From Marans/Stokols *Environmental Simulation* (1993).

reconfigurable" so that more information can be gained from multiple enactments.[23] This learning over time—or what we term *data generation* from a variety of input scenarios—is the simulational aspect of these fixed models. Note also that this use of fixed models can be a tactic for qualitative research; Augustin and Coleman's "users" imply live subjects, perhaps focus groups.

Colin Clipson classifies four types of simulation models: *iconic, analog, operational,* and *mathematical.*[24] The first two have more to do directly with physical contexts. *Iconic* models are used in the direct testing of materials or products under simulated conditions. For example, actual wall assemblies are tested for fire resistances; carpeting and other interior materials are tested under simulated conditions to determine their flame spread ratings. *Analog* denotes "dynamic simulation of an actual or proposed physical system." Flight simulators are of this variety. *Operational* models deal with people interacting within physical contexts; the data is generated by role-play. Hospital emergency room scenarios, or response to terrorist attacks, can be simulated in this way. *Mathematical* models are systems of numerical coding that capture real-world relationships in quantifiable abstract values; this is the domain of expanding computer technology vis-à-vis simulation. As noted earlier, increasingly the direction is toward computer models that integrate enormous amounts of information via databanks.

Again, when representations, whether two- or three-dimensional, are deployed such that they generate measurable data from dynamic interactions under various scenario inputs, simulation is taking place.

10.3.3 Prediction versus Projection/Pattern

Simulation gives us knowledge about possible real-world conditions without going through the ethical barriers, physical dangers, or financial expense of the actual conditions. Let's now consider further the kind of knowledge we can obtain. We have all taken part in fire drills to prepare for the likelihood of the real thing. But what do we learn? We don't learn anything that can accurately predict future behavior. But our experience in the simulation teaches us *patterns* of behavior, or *projections* of possible behavior, grounded in a realistically and hopefully rigorously prepared replica of the actual circumstances. In the World Trade Center simulation cited earlier, the authors ran through 50 computations each of 4 scenarios to obtain their results. In other words, it was the statistical composite of 50 sets of data that gave them confidence regarding patterns of behavior for the scenarios (e.g., with and without firefighters; with and without an intact stair from top to bottom; etc.). This is not to say that projection or pattern replaces prediction; it just increases the range—or perhaps the kinds—of predictive outcomes. Building Information Modeling (BIM), for example, can easily perform simulation studies of the predictive kind, such as modeling airflow, or the curing rate for concrete in a particular application.

10.3.4 Simulation Research in Relation to Experimental and Correlational Research

As previously described in Chapter 9, experimental research aims to test research hypotheses and identify the causal effects of key variables on outcome measurements. In this regard, a limitation of experimental research is that it is necessarily reductive; it isolates real-world variables in order to study the essential causal linkages within the phenomenon of study. In contrast, correlational research seeks to illuminate relationships among discretely measured variables in naturally occurring circumstances (see Chapter 8).

In contrast, simulation strategy aims to replicate in a holistic manner all the relevant variables in a setting or phenomenon. In other words, it can illuminate how a symphony (or perhaps a cacophony) of inputs all contribute to the holistic reality. When the behavior of that holism is simulated, we can then observe what significant variables are in play, and postulate further steps. William Crano and Marilynn Brewer put it this way: "A well-designed simulation has the potential to isolate the social phenomenon of interest without destroying its natural contextual meaning."[25] The holistic nature of simulation is both its attraction and its limitation. It is attractive because the simulated context promises a real-world view of a hypothetical situation. A corresponding limitation, however, is that the intentional "holism" of simulation cannot always be satisfactorily replicated (see section 10.4.1).

Nevertheless, the differing considerations of key variables of interest in the three research designs (experimental, correlational, and simulation) offer great potential for combining pairs of strategies in a mixed methods research design (see Chapter 12). Alternatively, as several examples in this chapter illustrate, simulation can be used as a very effective tactic within one of the other research strategies.

10.3.5 Simulation Research in Relation to Qualitative and/or Historical Research

For simulation research to be meaningful, accompanying research activities are required that are not strictly within the domain of simulation strategy. This is particularly true for analogue or operational types of simulation when human actors are involved. Often, data must be collected about the subjects before their participation in the simulation. This can involve interviews, checking records or documents, or other kinds of field work that have little to do with simulation strategy. Simulation can also be a tactic in historical research, that is, qualitative reenactments of past events or conditions. We provide an example of this in Chapter 6: Jean-Pierre Protzen's reenactment of how Inca masons might have dressed the stones for their large masonry constructions. This intermixing of other strategies for use as tactics in this one underlines just how fluid simulation research design can be. This leads to how simulation aids in theory building.

BOX 10.2

Computer Simulation for Historical Research

Computers aid research in historic structures. This study used computer modeling to show that the ornamental tracery on the hammerbeam trusses in London's Westminster Hall, built in 1395, actually plays a structural

(*Continued*)

role. The authors contend that the load-bearing behavior of these trusses had escaped thorough analysis through the years because of their complex configurations. Structural calculations by hand necessarily require "rounding off" to easier numbers. Computer calculations do not round off. What is more, computers can easily calculate "what if" scenarios.[a] In other words, it can simulate scenarios. In the study's truss diagrams reproduced in Figure 10.3, the lower one shows the much larger bending moments (dark areas) in a scenario in which the computer has deleted the ornamental tracery from the calculations.

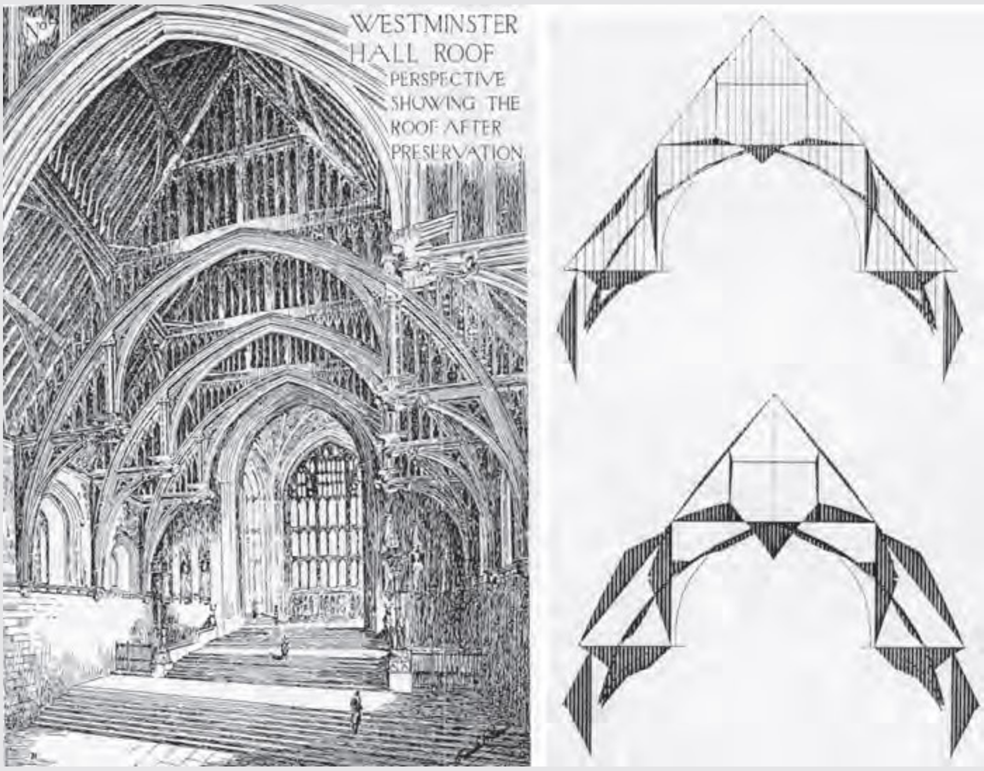

Figure 10.3 Left: Westminster Hall interior, by Sir Frank Baines, interior perspective (1914); Right: Computer models of the Westminster Hall truss using Finite Element Analysis. The lower diagram reveals larger bending moments when the ornamental tracery is deleted from the calculations. Courtesy of Stephen Tobriner.

[a] Toby E. Morris, Gary Black, and Stephen O. Tobriner, "Report on the Application of Finite Element Analysis to Historical Structures," *Journal of the Society of Architectural Historians* 54(3) (1995): 336–347.

10.3.6 Simulation Research and Theory Building

Simulation is useful both in developing theory and in testing theory. This is also a point made by Crano and Brewer.[26] They note that simulation research is often useful at an "intermediate" point of knowledge acquisition. That is, when a logical explanatory system has been framed (see Chapter 11), simulation research can help test, or at least enact, that conceptual system in an empirical venue. This is particularly true in theory-driven proposals for how physical environments can enhance (or otherwise alter or benefit) some aspect of life. For instance, full-size residential simulations provide data for affirming or disproving theoretical preconceptions; it can also provide material for new theory making.

One example of how simulation can be used at an "intermediate" point of knowledge acquisition is in the development of broadly conceived design guidelines (a form of theory that explains or describes a given object or setting, or how to realize such objects/settings). In the first edition of this book, we referenced Rohinton Emmanuel's research in urban heat islands: how orientation, size of windows, and paint colors can help in abating heat gain for residences in Sri Lanka.[27]

Advances in computer technology have pushed this kind of research further. In a study published in 2011, TRNSYS (a "transient simulation tool") calculated the impact of variations in street width, street orientation, and different roofing profiles on "urban canyon" heating. In other words, the authors researched both urban design and architectural design parameters in determining ideal guidelines for residential street sections vis-à-vis passive heating strategies. The authors found that street width significantly influenced the radiation yield of a residential street-to-building cross-section, while a street's orientation was less significant. They also found that single-pitched roofs on east-west-oriented streets produce higher radiation yields, and so on. These findings led to recommendations for future design guidelines.[28]

10.3.7 Simulation without Computers

As important as the computer has become for simulation research, it is important to remember that the computer itself is not integral to simulation as a strategy. Modeling scenarios to learn from them, as we suggested at the outset, is something humans were doing long before computers came along. Nothing about this changes with regard to simulation at the level of strategy. Even as this chapter is being written, the author was made aware of a simulated rhinoceros escape at a Japanese zoo. How can zoo workers prepare for such an eventuality? Two workers dressed up as the front and back ends of a rhinoceros on the loose, while other workers practiced setting up emergency fencing. One worker collapses to the ground, feigning injury by the rhino.[29] This is an elementary operational simulation, that is, role-playing by human actors. Of course, the accuracy of the simulation can be questioned. Humans have trouble simulating other humans (during terrorism scenarios, for instance, or as emergency room patients under duress); how can they know what a rhinoceros would do? But this is a critique of the simulation tactic, not a question about its strategy. Here is an example of simulation (without computers) used as a tactic in an experimental design. John E. Flynn and colleagues arranged a space in a lighting laboratory to look like a conference room. They then asked 12 groups (96 subjects total) to react to 6 different lighting combinations of overhead down-lighting and wall lighting. The authors sought to measure four factors: evaluative impression, perceptual clarity, spatial complexity, and spaciousness. Among other results, they found that overhead down-lighting scenarios, regardless of low or high footcandle intensity, were rated "hostile" and "monotonous" compared with options involving wall lighting.[30] This research used simulation: six lighting scenarios in a simulated conference room. Aside from not using computers, this example illustrates how simulation research can overlap experimental research. Box 10.3 and Figure 10.4 address another example of simulation without computers playing a direct role.

BOX 10.3

Operational Simulation with Actors

The following wording is supplied by Jacob Simons, NBBJ/rev: Simultaneously replacing a facility or undergoing an extensive remodel in order to integrate state-of-the-art technology and improved processes, all while managing excellent care delivery and costs, requires a departure from standard management and oversight practices. Without a doubt, every transition is an exciting opportunity to improve quality, safety, and performance, but for many, it is a "once-in–a-lifetime opportunity" that presents huge challenges and risks for the organization.

Simulations are conducted in the weeks before occupancy of a new facility. We fine-tune the environment (e.g., communication systems, equipment placement, faulty mechanical systems, etc.) and document all operational outcomes and design observations. This data is communicated to the firm to inform future projects. At Valley Medical Center, real-life scenarios were developed, with professional actors playing the roles of patients to test the entire system. Technology systems, staffing protocols, EMS staff, nurses and MDs, as well as the facility itself were put to the test—identifying critical environmental modifications as well as enhancing confidence among the staff before opening day.

Figure 10.4 Simulations with live actors at Valley Medical Center, Renton, Washington, a project by NBBJ, Seattle, Washington. Courtesy of Jacob Simons, Research & Design Lead, NBBJ/rev.

10.4 TACTICAL CONCERNS FOR SIMULATION RESEARCH

As we noted at the beginning of this chapter, replicating the real world is a difficult task, particularly if the goal is to obtain useful information from the simulated world to guide action in the real one. There are four general areas of concern: completeness of data input, accuracy of the replication, "programmed spontaneity," and cost/workability. These concerns also reveal the limitations of simulation research, and ways to overcome them are a large part of the tactics of this research strategy.

10.4.1 Accuracy of Replication

We return to the concerns noted at the outset of this chapter. Because simulation research seeks to replicate holistic real-world venues (in contrast, again, to experimental or correlational research), this implies embracing a potentially infinite number of variables. How can accuracy be achieved? Part of the answer depends on the type of simulation in question. In simulations of physical objects or materials, this is addressed by using the actual objects and/or materials in the scale that they would exist in the real world (e.g., full-size mock-ups). The simulation should take place with as many connections to the real-world setting as possible.

In iconic simulation, a product or material has to be tested in the very conditions (thermal, wind, geologic, etc.) in which the real object will be situated. Testing the color durability of window frames, for example, can be conducted by placing the full-size window in intense sunlight conditions for a prolonged period of time. The simulation might have to involve mechanical devices that can replicate the effect of sunlight. The same goes for a window's resistance to wind and rain: performance can be evaluated by mechanically replicating wind and rain impinging upon the full-sized window.

In analog or operational simulations, the actors involved should be individuals who are actually from the real setting. Sometimes professional actors are hired. But using actors and generating artificial climates obviously challenge the accuracy of replications. This concern increases when we deal in computer simulations, say, of complicated projections of urban growth, or how wildlife habitats would respond to alterations in urban infrastructure. In these instances, the need to "harmonize data" from a wide variety of databases is an increasingly demanding one; one resource is the Federal Geographic Data Committee (FGDC).[31]

There is probably no definitive answer to the question of how an artificially constructed scenario can be exhaustively accurate. Here, Herbert Simon's notion of "satisficing" is helpful. When Simon's *Sciences of the Artificial* first came out in 1996, the computer revolution was just getting started, but his insights are still relevant today for any kind of simulation research. Simon made the distinction between the inner world of the artifact (this can be a single object, such as a clock, or it can be society as a whole) and the outer world, the larger setting within which the artifact must function.[32] From this simple framework, Simon derived many insights. One is that we do not need to know everything about the inner environment of the artifact; the key question is whether it can fulfill its intended use in relation to the outer environment. Simon used economic forecasting and design of schedules for complex transportation networks as examples of large "inner" environments. He noted that computer models or models based in operations management are perforce simplifications of reality. But then he noted that these models usually forecast sufficiently well, or "good enough." That is, they satisfice.[33]

Simon's wisdom is that, when dealing with complicated systems, the best we can do is to understand the bounded domain of the system as much as we can, and then work along the lines of an agreed-upon set of assumptions to project its future trends. This does not exempt simulation researchers from care in defining the bounds of the domain they wish to simulate. But it does offer comfort in that "reality" itself may be more accommodating than a purely experimental approach may demand. Says Simon: "In facing uncertainty, standardization and coordination, achieved through agreed-upon assumptions and specifications, may be more effective than prediction."[34]

10.4.2 Limitations of Data Collection

Refer again to the first example we cited, the simulation of evacuations during the World Trade Center attack. Despite the computational power, the authors still underline the limitations that persist. For example, how do you model fatigue for both

BOX 10.4

Simulation for Friday Harbor Terminal, Washington State Ferries

Students at Washington State University's School of Design and Construction use Autodesk Revit and Autodesk Ecotect to simulate architectural and landscape conditions for a new design of the Friday Harbor ferry terminal in the Washington State Ferries system (Figure 10.5). Revit models topographical conditions of the land, while the Ecotect software inputs weather data from the region (this includes solar orientation and radiation levels, wind analysis, temperature, and rainfall patterns). Currently at this site, rain runoff goes directly into Puget Sound and inefficient queuing processes cause long loading times for getting cars on and off the ferry, especially during peak hours. Students can simulate scenarios for greenways and tidal parks, which treat the runoff before releasing it into the sound. The software also helps simulate alternatives for traffic routing to reduce the wait times. The Autodesk program can input massing configurations of the architectural form into the scenarios for more realistic studies.

(*Continued*)

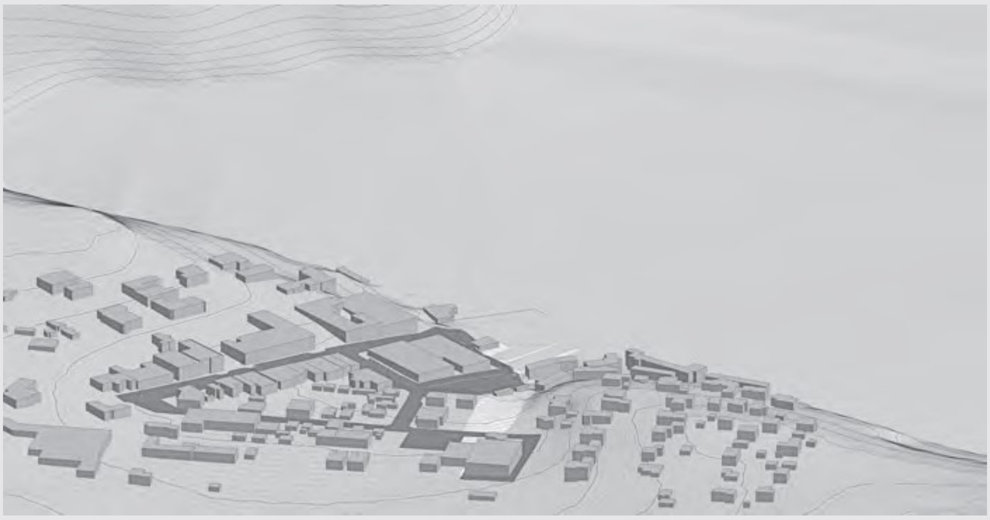

Figure 10.5 Students input preliminary designs of a greenbelt into a 3D site model, allowing them to see how the greenbelt will interact with the town and the topography. Using a model with all of this information allows designs to develop and progress while considering existing conditions. Courtesy of Allison Dunn and Jon Talbott.

exiting occupants and firefighters loaded down with equipment? How does the impact of group dynamics influence occupant response times?[35] Similarly, Robert Marans documents a study of hospital rooms that went through several mock-up iterations before the study was completed, each one made more "real" after assessing the simulated actions of the players (doctors and nurses) acting as themselves.[36]

These examples underline that simulated enactments themselves, whatever forms they take, are dependent on a variety of preenactment data collection. No matter how advanced simulation technology becomes, it is still dependent on the limitations of available data. These limitations take different forms.

First is simply that the data are *incomplete*. Consider evacuation of buildings during fire. In the first edition of this book, we cited Feliz Ozel's computer modeling of human behavior during fire emergencies (see Figure 10.6). To do this, she had to translate actual (reported) human actions into computer code. This required collection of data from the real event (where the fire started, the location of the 94 persons on the floor at the time, etc.). She concludes her paper by noting that relevant field notes from actual fire emergencies are so scarce that it is

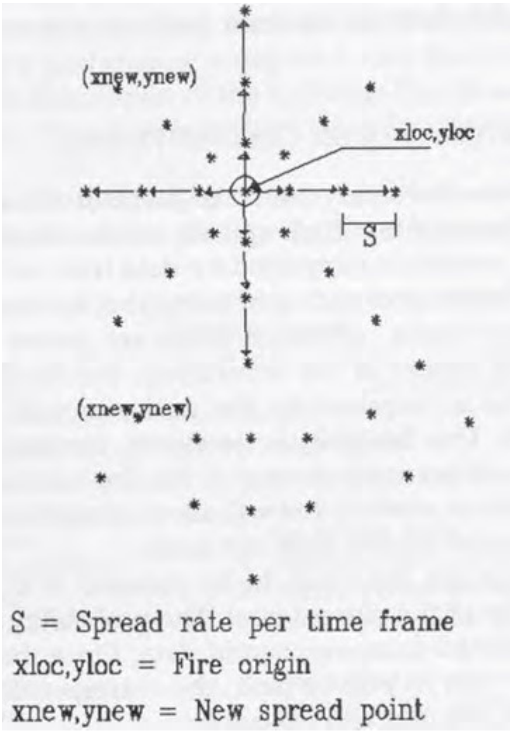

Figure 10.6 This 1993 diagram of a spread of a fire in a building, coded in computer terms, may seem simple compared to today's coding of complicated human behaviors. But the limitations are the same: translating data on human behavior into code that the computer can understand necessarily entails a reduction of real-life factors. Courtesy of Plenum Press. From Marans/Stokols *Environmental Simulation (1993)*.

difficult to test the accuracy of the patterns of behavior derived from computer simulations—and so it is incumbent upon the researcher to go and collect her own field data.[37]

The evacuation of the World Trade Center's North Tower was modeled with much more advanced computer technology, but the data collection limitations remained the same. The authors had to rely on estimates of the evacuation population from *USA Today*. Even so, the distribution of where these people were at the time of attack is unknown, so the authors had to assume. Also, some of the layouts of the floors, which were designed as open plans to maximize office flexibility, were unknown at the time of the tragedy; assumptions also had to be made.[38] The upshot is this: Ozel had to translate the actions of 94 persons into code; but Galea et al. had to account for over 9,000 persons. So even with the increased computing power, in what way does a hundred-fold increase in uncertainty about people movement and location affect the accuracy of the outcomes?

Second, the data are also *not spontaneous.* For example, in enactments of hospital emergency room operations, even professional actors still cannot fully replicate the spontaneity of human free agency. And of course, the individual receiving care in these instances, for obvious ethical reasons, cannot be a real case. The preceding Marans example is one way to improve the certainty: conduct multiple enactments, with a view towards learning iteratively from each enactment. And as noted earlier, in the WTC evacuation simulations, there were multiple computer runs (50) for each scenario, so that the final projections were statistical composites. Another way to overcome lack of spontaneity is what Clipson calls the *empathic* model, in which a role is played for prolonged periods of time by the researcher. The example is offered of one 26-year-old individual who, with meticulous makeup and costuming, transformed herself into an 80-year-old woman—and lived in this role for three years, three to four days per week. Clipson also suggests that participants who can internalize their roles will be more successful in generating realistic outcomes.[39] Linkages between these practices and qualitative research (e.g., ethnography or grounded theory) should be obvious.

Another aspect of spontaneity is currency of the data. It is true that computer technology can now integrate many different databases into one dynamic model (see Figure 10.7). But how current is the information in each database? If the dates of the databases are not generally current relative to each other, accuracy of the model can also be compromised.

Third, simulation data *must be interpreted.* The full-scale residential simulations mentioned earlier are an example. It is one thing to enact human interactions in full-size mock-ups of house interiors; it is another thing to actually derive meaningful results from the activity. In short, data had to be available to interpret the *meanings* of the decisions made by participants as they arranged the spaces to their liking. Specifically, Lawrence wanted to find connections between participants' past and present housing experiences to their present choices in giving shape to their next home. To do this, he had to collect information via interviews, as well as develop space syntax diagrams of the participants' past and present home plans. This meant that Lawrence had to draw from logical frameworks developed by Hillier, along with ones by March and Steadman. The study illustrates the stakes in discerning what kind of data must be included in the research design before a simulated study can have meaning.

10.4.3 Cost Limitations

Simulation research can be expensive: equipment costs, professional actors, stage settings for enactments, the time it takes to track down numerous databases, and

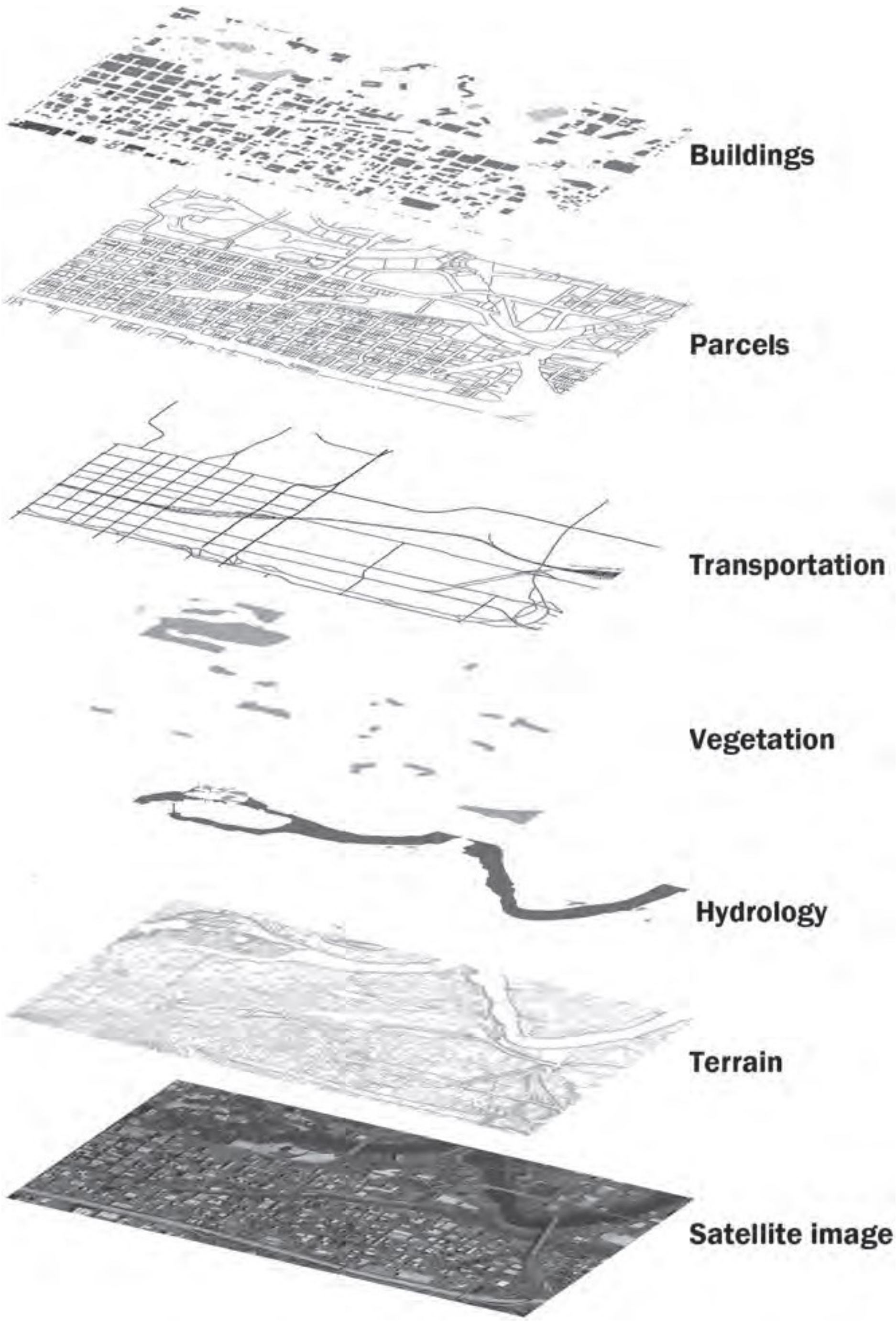

Figure 10.7 GIS layers. It is important for all of these databases to be synchronized in date for the resulting model to be dependable. Courtesy of Richard Xu.

then the permissions required to access them. Malkawi notes this explicitly with regard to immersive building simulation.[40] The hardware required is one form of cost. Another is the sheer technicality of the subject, which increases with computer sophistication; experts, as Malkawi notes, can be expensive. Earlier, in section 10.3.7, we noted that simulation does not have to be yoked to computer technology. One benefit of this is that simpler simulation studies, that do not use computers, can be less expensive as well. This helps simulation research in academic settings. Episodic (and hence less costly) efforts at simulation can have heuristic value while lowering expectations for strict data outcomes. We are referring to venues in which students can enact simulated experiences of design and/or practice, with the understanding that the "outcomes" can be viewed as having heuristic value aside from any "hard" data that might be produced. Full-size mock-ups of student designs are one example of what we mean. At Ball State University, Professor Wes Janz describes this third-year undergraduate studio assignment, along with its heuristic value:

> The project was the design of a pedestrian canopy for a public plaza on the Ball State campus. About halfway into the project, each student constructed a full-scale mock-up of a section of the canopy and hauled it across the campus in order to locate the mock-up in the exact place it was designed for . . . . The students interviewed passers-by regarding their designs, watched persons interacting with the mock-ups, and sketched a three-frame sequence that studied the pedestrian interaction with the canopy from a variety of distances. For the final presentation ten days later, each student selected a key detail of the canopy which he/she then mocked up at full-scale as well. This was in addition to plans, sections, small models, and perspective of the final canopy design. . . . Among the benefits to the students are the realization that the small, important models they do become infinitely more complex (and interesting) as they approach ideas about material, connection, and a way of thinking for the project."[41]

At Washington State University, Professor Nancy Clark-Brown designed a studio project in which her students simulated the practice sequence of programming, design development, schematic design, working drawing, and construction phase submittals. Because the studio was an interdisciplinary mix of architecture, interior design, and landscape architecture students, each student played the role of his/her discipline. The project itself was fairly simple: an "intervention" into a transitional space such as a monumental stairway or a corridor (see Figure 10.8). A key thrust of the effort was the operational simulation of actual practice. Clark-Brown

Figure 10.8 Installation of translucent panels in a grand staircase. The exercise gave an interdisciplinary team of design students (architects, interior designers, landscape architects) the opportunity to simulate a process of design, documentation, and construction with real-world time and budget constraints. Courtesy of Professor Nancy Clark Brown.

programmed restrictions into the process that mirrored limitations faced by the practitioner in actual practice: time restraints, budget restraints, construction restraints, and so on:

> [The] design process model provided a structure representational of a model used by professional design teams to structure project deadlines. . . . After defining the project goals and designing the intervention students completed a working drawing set to construct the project from. The construction time allotted was two hours and they were given a budget of $100.00 maximum per team for the purchase of materials. Students were allowed to prefabricate pieces necessary to the construction process prior to the installation of the project.[42]

Clark-Brown reports one heuristic outcome as follows: "students expressed a greater appreciation for the orientations of the distinct disciplines and made connections between them in the design process."

10.5 CONCLUSION

It is helpful to remember that the very nature of the discipline and practice of architecture, because it intimately involves "representation," deals with replications of reality. The added caveat is that architects deal with replications of reality that do not (yet) exist. Architects project new realities onto existing contexts, and thereby change those existing contexts hopefully for the better. We therefore want to return to how we began this chapter: the conflict between Plato's and Aristotle's views of representation. Plato was concerned about the dangers of *mis*representations: they can lead to false understandings of life; ultimately they stir morally undesirable ways to live. Aristotle, however, taught that narration of realities that *can* be (as opposed to realities that are) can have a positive influence. Architecture should heed both these insights, recognizing that the stakes, arguably, are higher in what it does. This is because architecture's goal is to make envisioned realities real ones. Its productions are not "just" about artistic works that continue to be demarcated from "real" life. Architecture's productions become part of real life. So in this sense we ought to give extra heed to what the strategy and tactics of simulation research can teach us. See Figure 10.9 for a summary of the strengths and weaknesses of simulation research.

Strengths and Weakness

Strengths	**Weaknesses**
We considered simulation's relationship with neighboring strategies earlier in this chapter. We conclude by noting that simulation may be particularly amenable for use as a tactic in other research strategies. In conjunction with other tactics, the data from simulation can be triangulated with data yielded by other means for more robust results. This certainly was the case, for instance, in Protzen's reenactment of Inca masonry fitting (see Chapter 6): had he only used the reenactment, his claims would not have been as strong as its use supplemented by other tactical findings. Triangulation of data from various tactics is indeed another means by which some of the limitations noted in section 10.2 can be overcome.	We considered the inability of simulated environments to ever be exhaustive representations of their real-world counterparts. And so the challenge is always to determine what amount of input data will lead to outcomes that, at best, in Simon's terms, "satisfice." We also noted the cost limitations of simulation research. In many cases, the challenge is to design simulation frameworks that are reasonable in cost. To help in this, it might be good to set up a scale of expectations for the outcomes, between "heuristic" for teaching purposes, to "measured" for actual applications in marketing or planning.

Figure 10.9 Strengths and weaknesses of simulation research.

NOTES

1. To be more accurate, Plato was not concerned about copies of "reality," but rather about copies of ideals of reality. Everyday realities, for Plato, were already copies of their ideal forms. For those interested in this, refer to his *Republic*, the seventh and (particularly) the tenth books. But this point is more fine-grained than this present chapter requires.
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environment, the surroundings in which it operates. If the inner environment is appropriate to the outer environment, or vice versa, the artifact will serve its intended purpose."

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34. Ibid., 42.
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38. See Galea et al., 87, 90, 92.
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42. Statement by Professor Nancy Clark-Brown given to authors, October 2000.