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Human behavior simulation in architectural design projects: An observational study in an academic course

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ABSTRACT

While previous human behavior simulation research indicates that autonomous, goal-oriented, anthropomorphic Virtual Users support iterations in architectural design, it is still unknown how the simulation can be used to iterate goals, potential solutions, and the match between them, and what can be learned from the simulation process and results. To investigate these topics, this observational study tracks and records the progressive refinements of four authentic architectural design projects of students, during an academic course. Findings of this study show that (1) the analytic experimentation of the simulation enables the students to iterate the goals relevant to the physical properties of design solutions responding to the behavioral performances of heterogeneous users, (2) the observable representation of dynamic users' behaviors inspires them to iterate the goals that reflect the psychological and social implications of solutions, (3) the simulation enables students to iterate potential solutions at different scales, ranging from masterplans, to prototypes, to design details, (4) in the final stage of iterating design solutions, the students iterated the parameters of Virtual Users to examine the full-performances of a final solution under what-if scenarios related to human behavior aspects (5) the students learn in the process of modeling detailed activities, and observing unexpected behavior outcomes during the simulation, experimenting the relationship between the properties of users and design solutions, beyond what they presumed. The evidence-based approach of this study reveals the applicability of human behavior simulation for the students' iteration and in-depth learning in the search for an optimal match between built environments and human activities in architectural design.

1. Introduction

Architectural design can be considered as a cycle of continuous learning by refining and reconstructing design goals via experimenting potential solutions (Kalay, 2004; Schön, 1983). The process of refining goals and solutions occurs by means of iterations. The aim of iterations is to modify either the design goals or solution to maximize the match between the two. This match is defined in terms of design performance. As one of the most fundamental requirements to be a professional architect, students are expected to be familiar with ways to systematically frame architectural problems and iteratively test solutions until the achievement of a satisficing condition (Rittel, 1971). Yet, some of the performance criteria that designers are expected to achieve in their design solutions pose serious challenges even to the most experienced practitioners. One of such challenges involves assessing the impact of a physical setting on the people that will inhabit it. This is a complex task due to the large number of variables that characterize human interactions with the built environment, such as perception, cognition, ergonomics, and social and cultural factors (Kalay, 2004).

At present, a common practice to assess human behavior issues during the design process involves extrapolation, a method for evaluating the performance of the proposed solution by comparing it to previous similar precedents. Extrapolation requires indirect inference from precedents, norms, and regulations. Since the nature of design problems and solutions is essentially unique (Rittel & Webber, 1973), such inference inherently faces gaps between new solutions and previous references. A different method involves direct-experience behavior tests that enable to observe the responses of actual human inhabitants to some proposed solutions both in real or virtual settings However, constructing realistic experimental settings both in real and virtual environments is expensive in terms of costs, times, and techniques. Furthermore, the method relies on a limited number of users, whose responses to the built environment may not be representative of the actual users.

To overcome the shortcomings of these approaches, simulation methods were proposed by several researchers (Chu, Parigi, Law, & Latombe, 2014; Ekholm, 2001; Kalay, 2004; Simeone, Kalay, Schaumann, & Hong, 2013; Tabak, Vries, & Dijkstra, 2010) to test design

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hypothesis or to evaluate undesired consequences of design solutions as far as human behavior aspects are concerned. The power of human behavior simulation lies in the ability to iterate the experimentation as many times as needed to test the relationship among variables interacting in complex and often unpredictable ways (Kalay, 2004). The rules of behavior embedded in the proposed simulation system can be deduced from observations of real life phenomena in settings similar to the simulated ones, or can be extracted by previous studies conducted, for instance, by environmental psychologists. While the previous simulation studies focus on the technical and methodological aspects about simulation tools and simulation model developments, empirical case studies that investigate how designers use human behavior simulation are have not been reported.

To address this issue, the present study intends to observe the use and application of human behavior simulation in authentic design projects developed by students in an academic course. The aim is to investigate how students used human behavior simulation to iterate architectural design goals and solutions, and what students learned from using human behavior simulation in their projects. The exploratory, evidence-based approach of this present study addresses the further applicability and affordance of human behavior simulation to architectural design education and practice.

This paper is organized as follows: a literature review that explores the applicability of human behavior simulation to design iteration is provided in Section 2. The research questions are presented in Section 3. The research method, including the information on the participants, projects, behavioral modeling, and data collection, is stated in Section 4, while the in-depth case analyses are detailed in Section 5. The conclusions and further discussions are outlined in Section 6.

2. Literature review

2.1. The role of simulations for design iterations

The architectural design process involves a set of iterations that designers perform to achieve a specific purpose by means of "progressive refinements" (Akin, 2011). Within iterations, architects define and redefine design goals in the attempt to discover an acceptable solution via navigating potential solutions (Kalay, 2004). Rittel (1971) clarified that in design iterations, architects should examine the variables and their relationship as follows: 'under context C, design configuration D will lead to performance P (1971, p.20)'. A design configuration includes the physical properties of a design layout generated and controlled by architects (e.g. form, shape). The context variables indicate the factors and constraints that influence the design solutions, but that are not controlled by architects (e.g. physiological, psychological aspects of people). The performance of a solution expresses the expected services emerging by the match between design configurations and design goals (e.g. safety, functionality). Iterations therefore allow (re)structuring goals and configurations to produce a desired performance under the given context.

The search for an appropriate solution, however, requires much time and effort because of the "wicked" nature of design problems (Rittel & Webber, 1973). According to Rittel and Webber's definition, design problems can be considered "wicked" in the sense that are unique, they depend on the formulation of the problem, and they have no optimal solution. A systematic way to experiment the interactions between the variables constituting goals and interactions is therefore needed (Kalay, 2004; Rittel, 1971), both in design practice and education.

Simulation is a means to iteratively experiment the dynamic interactions among variables to comprehend and predict the behavior of systems, such as the performance of an artifact under determined conditions (Shannon, 1975; Simon, 1999). Simulation methods enable successive testing of the behavior of a system to prove (or disprove) some hypothesized performance or phenomena by way of experimentation. These methods are particularly useful when the relationships among decision variables are too complex, conflicting, or dangerous to be tested in reality, such as space utilization in airports, hospitals, and industrial facilities (Wurzer & Lorenz, 2014). In particular, simulations allow testing "what-if" scenarios in virtual environment to explore possible solutions without commitment. Such strategy can be considered valuable to deal with the wicked nature of design problems.

While most simulation tools at architects' disposal focus on the prediction and evaluation of physical aspects of a building design (e.g. structure, energy, lighting, noise), fewer approaches investigated the possibility of using virtual humans to simulate the behavior of people in existing or yet to be built environments. Such studies assume that simulating human behavior allows designers to test the relationship between people, environment, and context through a trial-and-error strategy, and therefore to make more informed decisions at each design iteration.

2.2. Human behavior simulation in architectural design

Understanding the relationship between people and the environment that they inhabit is of primary concern in architecture and other social sciences. Whyte (1980) and Gehl (1987) investigated the capabilities of public spaces in supporting or hindering the performing of determined activities, such as sitting, resting, or having social encounters. The influence of the built environment on the behavior of individuals was also examined in terms of proxemics (Hall, 1966), personal space (Sommer, 1969), and crowding (Altman, 1975; Stokols, 1976). Barker (1978), instead, proposed a more general approach to examine people-environment interactions, based on the theory of "behavior setting". According to such theory, human behaviors happen in an environment (milieu), which is circumjacent to the standing patterns of behavior. At the same time, the behavioral patterns are also circumjacent to the environment (p.27). The aforementioned user-centered and evidence-based design approaches have been promoted to support architects in designing settings that support user needs (Gifford, 2002).

Capitalizing on such findings, pioneering studies proposed simulation methods to dynamically test the impact of a physical setting on users' behavior. This can be done by defining computable correlations between dynamic behaviors of agents, and the physical elements of built environments in which behaviors are performed. Hillier and Hanson (1984), Schultz and Bhatt (2012), and Hölscher et al. (2006) proposed a computational model to analyze the impact of the built environment on users' perceptual and cognitive abilities. Tabak et al. (2010) developed a schedule-based system to simulate human movement in office spaces. Chu et al. (2014) expanded traditional agent-based models for egress simulation to account for occupants' intimacy to social group, social structure, and social norms. Simeone et al. (2013) and Schaumann, Kalay, Simeone, and Hong (2015) developed a coupled process-based and agent-based system to represent complex use processes occurring in hospital settings.

To simulate human behaviors in built environments, Kalay and his colleagues (Kalay, 2004; Kalay & Irazàbal, 1995; Steinfeld, 1992; Yan & Forsyth, 2005; Yan & Kalay, 2004) proposed the creation of autonomous, anthropomorphic, goal-oriented agents, called Virtual Users (VUsers), which aim at representing the prospective users of a specific environment. VUsers are equipped with sensors able to detect environmental stimuli (such as the location of building elements, and the presence of other VUsers), and are able to respond to them according to social and cultural-based behavioral rules. VUsers behave according to a set of goals, which are achieved by performing a set of rules. Both goals and rules can be dynamically modified according to VUsers' personal characteristics, such as personality traits, preferences or physical and psychological status, allowing designers to simulate the behaviors of particular groups of users (e.g. physical disabilities or mental diseases) in not-yet built environments.