THE EFFECTS OF HUMAN BEHAVIOR SIMULATION ON ARCHITECTURAL DESIGN EDUCATION

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Abstract. Previous studies argued that human behaviour simulation is an effective analytic evaluation method to predict dynamic and complex human behaviour and social phenomena in not-yet built design solutions. However, its educational effects on architectural design have not been reported. The present study aims to investigate ways in which human behaviour simulation affects students’ feedback and design development. To achieve this, the study analysed weekly design productions, interviews and surveys collected in two experimental design courses using human behaviour simulation, held in the Technion – Israel Institute of Technology. In result, the analytic experimentation and observable representation of human behaviour simulation enabled students to evaluate and develop functional operability of buildings, accounting for users’ activities and social interactions, and develop design narratives relevant to social & cultural factors. However, the complexity of establishing & coordinating virtual people’ rules hindered fluent iterations of design development. Despite its technical limitations, human behaviour simulation has significant & unique educational advantages that can facilitate quantitative & qualitative aspects of design analysis, evaluation, & dynamic feedback to the students during design processes.

Keywords. Human behavior simulation, architectural design education, design analysis and evaluation, social and cultural behaviors.

1. Introduction
Architectural design education aims to teach methods that can help students predict and analyse human behaviour and social phenomena in not-yet built
design solutions (Rittel, 1971; Fitch, 1976). Nevertheless, current methods, such as extrapolation and direct-experience evaluation, are limited in examining and analysing complex and dynamic users’ behaviour in new design solutions (Kalay, 2004). In practical architectural education, instructors and students rely on norms, regulations, and case studies to infer occupants’ behaviour in their proposed solutions. Extrapolation methods, however, inherently face gaps between new solutions and previous references. On the other hand, direct-experience evaluations such as full-scale mock-ups and virtual environments, are expensive in terms of costs, time, and techniques to construct realistic experimental settings, being therefore ill suited for educational purposes. In addition, current design studio pedagogy does not have a systemic methodology to analyse and predict human behaviour in design solutions. Therefore, instructors and students cannot but rely on abstract, intuitive assumption and imagination, rather than instrumental exploration.

Human behaviour simulation was proposed by several researchers as a method that can help overcome the limitations of the current approaches (Kalay, 2004; Yan & Kalay, 2004; Tabak, Vries, & Dijkstra, 2010; Chu et al, 2014; Morgareidge, Cai, & Jia, 2014). Human behaviour simulation enables architects to iterate the experimentation as many times as needed, to obtain statistically meaningful results, and test the interaction of many variables that interact in complex and often unpredictable ways (Kalay, 2004). In addition, human behaviour simulation also represents observable processes of uses and interactions amongst occupants and built environments explicitly (Ekholm, 2001; Simeone et al, 2013), thus the analytics and representational aspects of human behaviour simulation may help analyse human behaviour in design solutions and evaluate them based on simulated outcomes.

While such potential stems from several pioneering studies on human behaviour simulation, most of them focus mainly on simulation models and technical aspects rather than educational effects. Instead, the present study aims to investigate ways in which human behaviour simulation assist students’ learning and feedback for design development in empirical architectural design courses.

2. Literature Review

2.1. HUMAN BEHAVIOR SIMULATION

Simulation is an experimentation method that can be used to iterate the hypothesized relations amongst decision factors, for the purpose of comprehending and predicting the operability of systems (Simon, 1999). Extended from that definition, human behavior simulation aims to analyze and predict
performances of a physical layout, based on human users’ behavior rules in a real-world system (Kalay, 2004; Morgareidge, Cai, & Jia, 2014). By means of human behavior simulation, the relationships among the variables of physical environments and human factors could be tested through a trial-and-error strategy, thus architects can alter iteratively the hypothesized solutions until they reach a satisfying performance from a human performance point of view.

To simulate human behaviors in built environment, Kalay and his colleagues (Steinfled, 1992; Kalay & Irazábal, 1995; Yan & Kalay, 2004) proposed the creation of autonomous, anthropomorphic, rational agents, called Virtual Users (VUsers). VUsers are equipped with sensors able to detect environmental stimuli and are able to respond to them according to social and cultural behavioral patterns. They generate the responsive behaviors according to a set of rules and goals, based on personality traits, preferences or physical and psychological status in real-worlds. Recent advancing game engines are applied for representing the dynamics of VUser’s behavior in a 3D environment, along with a computational set of goals and rules (Figure 1).

![Figure 1. Be’er Sheva public park design (Weisman, M. et al, Technion, 2013).](image)

2.2. ANALYTICAL AND REPRESENTATIONAL ASPECTS OF HUMAN BEHAVIOR SIMULATION

Many previous studies have emphasized the capability of human behavior simulation for analyzing very specific aspects of human behavior. Jalalian, Chalup, and Ostwald (2011) analysed circulation patterns, speed, and direction of pedestrians responding to attractive objects in urban spaces and streetscapes. Morgareidge, Cai, and Jia (2014) applied human behavior simulation for analyzing the decision-making capital, operational costs, and organizational performance relevant to layout and distance amongst departments in a hospital. Chu et al (2014) investigated a new agent-based egress simulation model, called SAFEgress. This model aimed to analyze evacua-
tion patterns and performances responding to social parameters - group affiliation, social order, and assigned roles.

From another view, several studies have focused on representational aspects of human behaviour simulation for design evaluation. These approaches provide more holistic dynamic 3D visualizations of how buildings are used by their occupants. Ekholm (2001) argued that the representation of users’ activities might be helpful in the design development phase to enhance functional aspects of buildings, such as the distribution of spatial functions, and comprehend temporal building use and versatility. Simeone et al (2013) also argued that representing comprehensive use processes might enhance architects and clients’ communication, building performance evaluation, and process planners’ workflow management relevant to the operability of building facilities. To simulate and coordinate massive numbers of VUser’s behaviour, they proposed an integrative representation system combining Business Process Modeling and Notation (BPMN) and 3D game engine. A game engine computes and represents the information generated by the BPMN, such as schedules and time, by applying it to the proposed physical setting in order to provide a dynamic representation of the building use phenomena.

However, while these previous studies have demonstrated the potential of human behavior simulation for user behavior analysis in not-yet built environments, most of them focused on technical development and quantitative analytics of the simulation, rather than on its educational affordances in architectural design. Empirical evidence-based approaches, which investigate ways in which students use human behavior simulation for design developments, are still rare.

3. Purpose of Research

This paper aims to investigate in what ways human behaviour simulation impacts students’ design development in empirical design courses. In particular, the paper examines the following research questions: (1) What kinds of design topics and goals can be simulated by students? (2) Which types of information students learn from human behaviour simulation, and how they develop their solutions accordingly? (3) Which characteristics of human behaviour simulation enable or obstruct students’ analysis and evaluation in their decision-making and design development?

4. Research Method and Process

To achieve the research goals, we applied qualitative analysis methods in two experimental design courses using human behavior simulation, held in
spring semester 2013, 2014 at the Technion – Israel Institute of Technology. These courses aimed at teaching application methods and implementation techniques of human behavior simulation to support the design of different types of social places proposed by students. The curriculum of these courses was 14 weeks long, with class meetings once per week for 3 hours. The first half of each course taught students how to investigate environmental variables and types of users at their chosen project sites and set up desired performances characteristics of their design solutions in terms of users’ activities. In addition, several weekly assignments were provided to develop the solutions without relying on human behaviour simulation. The second half of each course was dedicated to design developments with the use of the simulation. The simulation process consisted of populating VUsers in the design, which behaved according to rules previously encoded in the simulation system. By observing VUsers’ behaviours and their social interactions in the designs, students were able to analyse and evaluate whether the performances of their proposed solutions support users’ activities or not. Based on these processes, they simulated possible behaviors and events of users in alternative design solutions and iterated the solutions until they satisfied desired performances goals.

21 undergraduate students (in their 4th and 5th year) at the Faculty of Architecture and Town Planning participated in the course, in nine teams. The students modeled physical shapes and motions of anthropomorphic agents (VUsers), using 3D animation software Autodesk 3DS MAX, and set up the behavioral rules, population amounts, and traits of VUsers in commercial 3D video game engines, Dassault Systèmes’ 3DVia Virtools and Unity 3D.

During the courses, weekly assignments – videos of the simulation outputs, snapshots, and diagrams – were collected and analyzed to track the students’ design development. After completing the courses, paper-based interview and surveys were conducted to investigate (1) application scopes of human behaviour simulation, (2) effects of the simulation on learning and design development of students, focused on the feasible performances and narratives of design projects to support users’ activities and social interactions, and (3) limitations of the simulation on learning and design development of students. The aim of the interviews and surveys was to investigate students’ internal communication and decision-making processes, namely – which types of information they received from the simulation, and how they affected their design development.

During the courses, students first defined the goals of their projects to support physical and ergonomic behaviour of users, like accessibility, safety, comfort, visibility, and efficiency. To test these desired performances, they simulated VUsers’ circulation patterns, durations, conflicts, distances, and
bottlenecks, in response to the physical properties of their designed solutions, such as dimensions, shapes, and location. Second, students tried to evaluate the occurrences of social interactions in their design solutions, by observing the frequency and location of interactions among VUsers in hypothesized physical layouts. Third, several design projects aimed to infer psychological and cultural behaviour of users by analyzing VUsers’ responses to cultural and social norms.

5. Results

In the Be’er Sheva public park design, student M, L, and E populated a large number of virtual visitors, programmed to generate behavior responding to the attractive objects in the park while they travel between the different zones in the park, such as a water pond, a grass meadow area, and a playground area. By simulating the users’ behavior, the students analyzed the circulation patterns, distances, and densities of the designed zones, and evaluated the cohesive connections and functional operations among the zones to support visitors’ comfort and accessibility (Figure 2). Student K simulated and iterated the width, location, and numbers of ramps to access other floors in a skyscraper’s lobby, and discovered the optimal layout that supports the most fluent and comfortable circulation and social interactions of users (Figure 3).

Students also reported that they have learned to develop both functional and social aspects of design by analyzing possible users’ behaviour narratives. For example, student D, O, and C simulated pedestrians’ circulation patterns under two narratives: one is a normal daily condition, the other is a weekly event such as protest (Figure 4). In the Hof-Ha Carmel bus station design, student M, E, and A analysed circulation patterns, accessibility, and bottlenecks in front of a security entrance booth when a large number of passengers started from the designed waiting spaces to the bus parking lots (Figure 5).

In addition, the simulations allowed students to analyze human behaviour social factors and ergonomic aspects. For example, students I, R, and B developed loop-shaped street furniture units: they observed and examined in what ways curvature, shape, and dimension of the units supported possible programs, such as street retailers, performance stages, and benches, from the view of pedestrians (Figure 6). In another example, students A and D analyzed the frequency of social interactions among software engineers and hardware technicians in the IT office layout and developed the layout to support the maximum daily interactions (Figure 7). In the Bedouin community centre project, students C and I applied the cultural norm of the Bedouins,
which prohibits females from meeting males, to analyse daily and emergency circulation and accessibility of Bedouin females (Figure 8).

Figure 2. The circulation in the public park design (Weisman, M. et al, Technion, 2014).

Figure 3. The circulation in the tower lobby design (Reznic, K., Technion, 2014).

Figure 4. Bottleneck in the street protest event (Rudich, C. et al, Technion, 2014).

Figure 5. Circulation when passengers board a bus (Burmad. M. et al, Technion, 2014).

Figure 6. The atypical street furniture evaluation (Muzychuk, I. et al, Technion, 2014).
6. Analysis

In the interviews, when asked how human behavior simulation facilitated their learning and design development, students mentioned the ability to evaluate their design solutions’ functional feasibility. Representing traveling paths, time measurement, and counts of users enabled the students to compare the performances of several design alternatives explicitly. Iterative experimentation also allowed students to find an optimal match among many design targets. Watching real-time interactions of VUsers provided opportunities to discover new possible functions in proposed layouts and thus helped them calibrate design goals and narratives in order to contain more social interactions. Students also noted that this observable representation was a convenient means of communication to share evaluation results with team members.

Applying human behavior simulation is technically difficult. Students had to master complex procedures to coordinate VUsers’ behaviour rules to achieve a stated goal. The simulation model, applied in the courses, was based on autonomous, individual agents, and thus whenever students simulated different narratives, they had to re-establish and coordinate the parameters of massive amounts of agents. Such coordination required skills and high workloads to learn scripts and interfaces.

Students also noted that they had a methodological difficulty to extract valid and reliable behavioural rules of VUsers from complex phenomena of real-life behaviour. To define the rules in the simulation, students calibrated types, scopes, and details of behavioural units in order to meet project goals. While learning research methods to extract human behaviour in reality was not in the scopes of the two courses, students mentioned that the extraction and abstraction of behavioural rules was essential to convince themselves and others in cycles of design development.
6. Conclusion

The paper reported on the application of human behaviour simulation in empirical architectural design courses. We found that students were successful in applying the simulation for design projects, intended to support physical and ergonomic behaviour of users, occurrence of social interactions, and psychological and cultural behaviour of users. The actual scopes of application were more diverse than those reported in previous studies, which mainly focused on analyzing physical behaviours (Jalalian, Chalup, & Ostwald, 2011; Morgareidge, Cai, & Jia, 2014). In addition, experiments reported here found that both analytic experimentation and observable representation of human behaviour simulation helped not only develop functional operability of spatial elements, but also inspire social narratives and events, and qualitative atmosphere and comfort, which previous studies have not discovered (Ekholm, 2001).

The limitations of applied simulation model in the present study were mainly due to the focus on agent-based simulation, which is not a sufficient model to handle complex narratives in empirical design projects. Perhaps, a convenient coordination system can be applied to improve the current model (Simeone et al, 2013).

In conclusion, despite several technical and pedagogical limitations, this study found that human behaviour simulation has significant and unique educational effects that facilitate both quantitative and qualitative aspects of design analysis and evaluation, and thus provides and inspires opportunities for further design development and learning of students.

The study relied on in-depth qualitative approach to comprehend latent impact factors of human behaviour simulation on architectural design development of students. However, this study did not intend to capture statistical performances of the simulation compared to other conventional evaluation methods. Future study will recruit larger numbers of students for the quantitative approach. As pedagogical implications, this study recommend that human behaviour simulation can be applied for architectural design studios, social factor-emphasized design courses, and human behaviour analysis courses as an evidence-based approach. Interdisciplinary teaching based on the simulation and human behaviour studies, like environmental psychology in particular, is also recommendable to establish valid and reliable behavioural rules in human behaviour simulation.

Acknowledgements

This research was sponsored by a grant from the European Research Council (908040 FP-7 ADG) and a grant from the Israel Science Foundation (890015). We also appreciate the help and motivation of all the students who took part in the course “Designing Social Places in
Online, Multiuser Virtual Environments”, held in the spring semester 2013, 2014 at the Faculty of Architecture and Town Planning, Technion.

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