Dragonfly
AN ECOLOGICAL APPROACH TO DIGITAL ARCHITECTURAL DESIGN

ABSTRACT
Dragonfly is a simulation engine that extends the scope of current human-space interaction tools by encoding the basic principles of ecological psychology into an interoperable, interactive, CAD environment.
1 Introduction

In his keynote address, delivered to The American Society for Esthetics in 1976, James J. Gibson wrote, “Architecture and design do not have a satisfactory theoretical basis.” He then asked, “Can an ecological approach to the psychology of perception and behavior provide it?” (1976, 413) We believe that it can, at least in part. In this paper, we expand upon Gibson’s insights into the nature of perceptual experience by applying the concept of “affordances” to the design of architectural objects in general, and to the domain of digital architectural design in particular. By our account, the affordance-concept supplies a useful theoretical basis for conceptualizing the relationship between environments and occupants with respect to the form and behavioral meaning of geometrically constructed layouts.

Donald Norman (1988) first introduced affordances to interaction design theorists, as a conceptual tool for predicting how agents will interact with a given product. The extensive body of literature that has since emerged, from human-computer-interaction studies (Ackerman, 1996; Conn, 1995; Moran, 1997; Norman, 1999) to architectural theory and practice (Koutamanis, 2006; Maier and Fadel, 2009), has followed Norman’s lead in defining affordances, somewhat amorphously, as whichever action-related properties of objects are sufficient to elicit the intended forms of behavioral interaction between agents and objects. However, while this is correct, it is only half the story. It leaves unexplained how human perceivers detect and “pair down” on the potentially vast range of possible affordances (at a given time), to select the ones that will be relevant to the coordination and guidance of the targeted actions. Call this the “selectivity problem,” a proper treatment of which is missing from the literature. This is no small matter. If the theory of affordances is to be useful to architects and designers, if it is to have explanatory and predictive power over how perceivers will interact with their surroundings, then some account of the cognitive procedure by which affordances are selected for the deployment of specific behaviors is necessary. Otherwise, it is unclear what the theory hopes to predict or explain.

To this end, we maintain that the couching of affordances in a framework of human intentionality is not only consistent with Gibson’s theoretical views (i.e., the action-oriented definition of the concept of affordances not only suggests an intentional perspective), indeed, such a perspective is necessary if we are to succeed in implementing the affordance-concept into an architectural design context in a way that addresses the selectivity problem. This is one of the goals of “Dragonfly,” a first attempt at implementing the affordance-based control of perceptually guided-action into a digital design simulation. Dragonfly enables human interaction with geometry by encoding the basic principles of ecological psychology (including a rudimentary form of intentionality) into an interactive CAD environment. New vistas for future research and interdisciplinary approaches to design are then discussed, with a special emphasis on their applicability to architecture.

2 Gibson’s Theory of Affordances

Generally speaking, the ecological approach to perception reflects two main themes that distinguish Gibson’s views from his predecessors and opponents. First, perception is a relational achievement of perceiver-environment systems, rather than a private achievement of an individual’s brain. Accordingly, what makes up the environment of a particular individual, including both natural and artificial features, is part of this theory of perception. Second, perception’s primary function is not mere representation as such, but rather the guidance and adjustment of an individual’s behavior with respect to the environment. So, the kinds of activities that a particular person does are part of this theory of perception as well. To look ahead, Gibson uses the affordance-concept to capture the tight, dynamical coupling of the perceiver and the environment. This will become clear in what follows.

This approach to perception assumes that our perceptual systems have evolved, over time, to take advantage of objectively existing information. The aim of the study of perception is to identify that information, discover what it specifies, and determine
how it is “picked-up” by an observer. Such an enterprise must begin naturalistically, with perceivers in free movement through the ordinary environment. To understand why, we need to enlist another Gibsonian concept: the optic array (Figure 1).

Think about walking across one of the elongated corridors in a hotel building. The corridor across which you are walking includes an infinite number of potential points of observation. Each point is surrounded by a “shell” of optical structure; light is reflected to it from all directions. To clarify, consider the point at which your right eye is now located. One sector of the structure available there consists of light from the right-hand wall; another sector of light is perhaps reflected from a picture on that wall. Other sectors are the ceiling, the doorways, the vending machines, the maids’ trolley, and so on. Every shift to a new point of observation alters that optical structure and initiates a systematic optic flow, which precisely specifies the movement that produced it. It is optic flow, more than anything else, that enables the perception of self-movement with reference to the distal layout of the environment. As Michael Turvey puts it, perceived information does not need to be constructed out of discrete sensory inputs, but rather, “the centers of the nervous system, including the brain, resonate to [environmental] information.” (1992, 93)

In Gibson’s ecological theory of perception and action, perception is not based on the stimulation of receptors by physical energies, but on the pick-up of higher-order information in reflected light by a mobile observer. It is by attending to the invariant structure preserved across transformations of the optic array that we can orient our activities with respect to our surroundings. Consequently, the higher-order or “invariant” structure of the optic array points in two directions. On the one hand, it conveys information about the formal properties of objects, such as their size, shape, and trajectory, and on the other, it specifies what individuals can do with and in the environment. As Gibson conceives it, the concept of affordance refers to these perceivable functional properties of objects and events that are carried in the structure of reflected light. He writes, “The affordances of the environment are what it offers … [perceivers] … what it provides or furnishes, either for good or ill.” (1979,129) In its simplest formulation, then, the affordances of a given place in the environment establish for an individual what actions are possible there and what the consequences of those actions are. To give a simple example, a surface in the environment may be perceived as “sit-on-able” in relation to a particular individual if it meets certain criteria dictated by the features of that individual’s body. For instance, the surface must be appropriately scaled to appear supportive of the individual’s weight, and be positioned approximately knee-high. The more a surface deviates from these criteria, the less it will be perceived as offering the relevant functional property, namely, the affordance of sitting.
In the next section, we aim to increase the cogency of this claim by situating the affordance-concept in an intentional framework. In so doing, we hope to display its applicability to architectural design, by allowing for a theoretical basis upon which to improve the design process. To glance ahead, we conclude the paper with a practical application of the theory of affordances (along with the auxiliary concepts discussed in this section) into the Dragonfly simulation model.

3 Selectivity, Intentionality, and Design

There appears, at first blush, to be a problem in the way Gibson characterizes affordances. For Gibson, the aspect of perceivers to which affordances are relative is cashed out solely in terms of body-scale. This view is endorsed by most empirical design studies which follow Bill Warren's (1995) application of the affordance-concept to the design of specific artifact-user relationships, such as the height of stair steps. However, while body-scaling is certainly an essential characteristic of affordances (e.g., door handles must be scaled to the size of an individual's hand if they are to afford turning), it falls short of explaining the process by which individuals "pair down" on the range of affordances potentially available to be engaged, in order to extract task-specific information for the realization of particular goals. We call this the "selectivity problem." For example, a toddler in a preschool playroom has available to her a plethora of functional opportunities presented by the furnishings as a result of their design and structural properties, and considered in relation to that child. There are chairs to sit on, tables on which to work, playhouses to play in, objects to manipulate, and so on. However, a properly scaled chair also affords the child a place to draw and color, a refuge for hiding, a podium for shouting, or something to kick over in a tantrum. These and other functional opportunities are built into the affordance structure of this common playroom artifact. So, how does the child succeed in selecting the "correct" affordance to be exploited in the execution of a particular task?

Gibson does not consider this question, nor do architectural designers who have attempted to utilize affordances as a conceptual framework to understand the relationship between environments and occupants, especially with respect to form and function (Maier and Fadel 2001, 2009; Brown and Blessing 2005; Koutamanis 2006). In architectural design areas, the term "affordance" is simply used to indicate "the potential for behavior" rather than the "actual occurrence of that behavior." (Maier and Fadel, 2009, 397) However, the user-relative conditions under which environmental features show up as eliciting certain forms of behavior, instead of others, is crucial for the implementation of affordances in graphical design (see next section). In our view, the specification of functional opportunities refers to the individual in a more significant way than mere body-scaling per se. Following Harry Heft (1989, 2001) and Aaron Ben Ze'ev (1984), we maintain that affordances are to be identified in relation to the body as a means of expressing goal-oriented "intentions." So, instead of identifying an affordance relative to the size of a particular body feature, the specification itself is to be couched in relation to the body as it participates in goal-directed behaviors, which is to say, "An affordance is perceived relative to some intentional act." (1989,13) To return to our previous example, whether a door handle affords turning for an individual must be assessed relative to an intentional act (i.e., grasping-to-turn) and not only with respect to hand size. Based on our account, the interaction of functional characteristics of the environment and the physical dimensions of an agent's body both constitute and constrain the range of intentional acts that can be instantiated at a given time and location.

An intentional analysis of affordances "brings to the forefront the matter of the locus of functional meaning" (Heft, 1989 15) in all environments, be they natural or artificial, real or digital. It suggests that the perceived meaning of an object resides neither in the object itself, nor in a mental representation in an individual's mind; rather, it emerges in an intentional relationship between them. Meaning, aesthetic as well as practical, is not added to raw sensations or given to the world of physical stimuli. In the course of an individual's ongoing activity, meaning is revealed in the
environment in conjunction with particular intentional actions. Needs control the perception of affordances, and also initiate the activities that seek them out. Thus, among the affordance possibilities of the environment, some affordances will be selected in the course of the individual’s interaction with the environment (to the neglect of others). By bringing out this intentional quality of Gibson’s theory, we can begin to make sense of the selective nature of affordance-perception.

4 Application to Architecture

In architectural practice, understanding the interplay between the varied needs of individuals and the functions of the environment in which they reside is still very much a matter of the designer’s intuition. All architectural objects, from the tallest skyscrapers to the smallest pavilions, should permit a variety of functions dictated by the user’s needs. The degree to which those functions are successfully “picked-up” by the user is in many ways a measure of the success of the design. Program, like perception, is a functional relationship that emerges between an object and a user. Thus, an effective design is one whose structure elicits the desired forms of behavior from the user.

The interaction between human users and geometry is called space syntax, a term originally coined by Bill Hillier and Julienne Hanson in the late 1970’s, at approximately the same time that Gibson was developing the theory of affordances. Space syntax differs from perception insofar as the geometry with which users interact conveys no higher-order information (i.e., affordances), nor does it affect the actions of users, save for those that govern navigation of the space. Over the past three decades, the study of space syntax has grown to include a number of different analytical methods, full integration with GIS data, and parametric modeling. Initially, this type of analysis was used to verify the effectiveness of proposed developments, road networks, or floor plans, but has since been applied to form finding and conceptual design.

A natural question is: how accurate are the results of this application? Can we reliably predict how humans will interact with a floor plan? The problem lies in the fact that it is difficult, if not impossible, to digitally emulate human behavior in all of its subtle complexities. This does not mean that simulation environments are not useful tools. On the contrary, simplifying complex problems often brings to light important insights that would otherwise remain obscured by their complexity. The key is to understand the driving parameters of the simulations, and to respect their limits. In the case of current space syntactical methods, a crucial limiting factor is that such methods fail to account for either the intention of the users within the simulation or the intended function of the artifact or design. Accordingly, we argue that existing human/space simulation tools are incomplete when applied to small-scale simulations geared towards understanding the user-intentions and the intended functions, or program, of architectural layouts. Indeed, a central aim of this paper is to broaden the methods of space syntax by encoding the basic principles of ecological psychology into a digital model.

While both space syntax and ecological perception have been extensively researched and written about, the relationship between the two has not. There are, however, some simulation tools that do attempt to examine user-interaction with geometry. For instance, crowd simulations attempt to mimic crowd flow through different environments, while adhering to rules that govern the overall direction of flow (e.g., sinks and sources) and the distance between agents (i.e., people). Although most crowd simulation engines have been developed for the computer graphics industry, there are a few that have been applied to architecture (see Penn and Turner 2001; Sharma 2007; Narian et al. 2009).

In general, human movement engines make use of one of two techniques: global and local movement calculation methods. Making a global decision for the overall pattern usually consists of viewing the group of agents as particles in a continuum. By informing the specific parameters of the continuum, such as density and viscosity, adding attracting and repelling regions as well as containing geometry, the path of
travel of any group of points within the continuum can be readily computed. While it has often been noted that the movement of large crowds seems to resemble fluid flow, the accuracy of that resemblance to human intentionality has not been substantiated. For example, the movement of the fluid is not self-motivated – it must be propelled by attracting and repelling regions. If these were removed, the fluid would be stationary, which would not at all resemble the behavior of a crowd of people trapped inside a building. On the other hand, local movement calculation methods enable individual agents in the simulation to make decisions about how and where to travel, and is more akin to the general case of pedestrian movement. While Dragonfly makes use of local decision making, an important difference between our implementation and existing simulations is that Dragonfly recognizes the influence of the architectural layout in determining the range of intentional behaviors that are possible, and not simply that of the agent (Figure 2).

More specifically, Dragonfly uses two distinct modes to simulate the relational achievement of perceiver-environment systems. The first mode allows users to navigate a 3d model from a first person perspective via the WASD keys and mouse, similar to game-world interaction. By restricting movement to floors, ramps and stairs, the user can evaluate how effective the proposed layout is at conveying information about way-finding. To empirically evaluate the affordances of the model, the user is prompted to select a profile that specifies the intentions with which they will perceive the model. However, since perception is a relational achievement between environment and perceiver, the model must also contain data concerning intentionality. Our implementation allows users to specify the intended function of a particular region of the model as object metadata. Pressing the affordance toggle (TAB) will highlight which objects in the user’s viewshed afford some kind of behavior - clicking on one of the objects will select the affordance relation they wish to pursue. That data is then added to a collection of statistics that can be reviewed at any time. This mode is intended to study how effective a proposed design is at conveying functional meaning to the users of the space.

The second mode populates the model with a set of agents. Each agent is assigned a profile (similar to the user profile) and additional behavior guides. The guides, such as “exploratory,” “cautious,” or “determined,” tell the agents how to select one affordance from the list of possible ones. The agents then navigate space using the optic array, which we have implemented using a modified isovist algorithm, until they see, in the algorithmic sense, geometry (i.e., a wall, window, or doorway) that has been activated by one of these programmatic regions. In the ecological sense, however, agents will only perceive the geometry as affording a certain function if it fits with their intentions. Although in this mode the choice of which affordance to pursue is essentially predetermined, and is only meant to reflect certain aspects of human interaction with space, the overall interaction of the agents with the model is still very complex. By studying it, designers can quantify aspects of how effective the proposed design is at conveying its intentions.

5 Synthesis and Conclusion

Our proposed digital environment, just like the real environment, is composed of a nested set of surfaces with a certain geometrical structure - and similar to real perception, the user’s “field of vision” is constituted by a field of rays projected from all directions to a point whose global structure undergoes systematic changes as the user moves through its environment. The invariants of that structure, which emerge through perspective transformations, allow the user to detect the persisting geometrical layout while simultaneously informing its subsequent behaviors in a perception-action feedback loop. For users, the selection of the affordances is based upon their user profile and the available metadata of the model. The agents, however, must possess a rudimentary form of intentionality if they are even to begin seeking out the affordances that will permit the realization of their programmatic intent. Dragonfly accomplishes this by allowing the user to assign profiles and behavior guides to the agents. The interaction of the guides and profiles determine how the agents will navigate and interact with the model, for example exploratory
agents will seek to avoid previously explored areas, whereas cautious agents will seek to stick to familiar ground. It is important to note that many very advanced behavior guides (i.e., artificial intelligence) algorithms already exist – our goal is to apply these guides in our simulation environment, not to develop them for their own sake.

In summary, the agent - just like the person - forms an integrated system with its environmental surroundings. On the basis of perceptual information concerning the agent’s location and trajectory, which is constantly being updated by its movement, the agent is able to perceive the distal features of its environment and guide its behaviors with respect to them. However, unlike a person, the agent must possess specific instructions if it is to “pair down” on the total range of affordances available to it. This inability to pick-up on some affordances and neglect others underscores the need for a way of interacting with the geometry in a non-deterministic way, namely, via user profiles and first person navigation controls. By switching between the two modes, it is our hope that the effect of geometry on human behavior will be conveyed clearly to the user.

As this application of ecological perception to digital architectural design is still very much in its infancy, our results are correspondingly preliminary. Nonetheless, the simulations we have run to date reinforce a fairly common-sense principle in architecture, which is the importance of view lines. A user entering a new building cannot hope to navigate it successfully without being given visible clues that lead her to utilize the intended program of the space. The importance of visible clues to the usefulness/usability of a design has been most comprehensively studied by Donald Norman (1988). While affordances indicate the range of possible activities, “[they are] of little use if they are not visible to users.” Hence, “the art of the designer is to ensure desired, relevant actions are readily perceivable” (1999, 41).

Currently, we are in the process of expanding the kinds of affordances available in the simulation, based on Gibson’s (1976) proposed list connecting geometry types to affordance-possibilities. Attaching detailed information to objects is a powerful trend in the AEC industry, as evinced by the widespread acceptance of Building Information Modeling (BIM) tools. Accordingly, we expect Dragonfly to leverage that detailed information (e.g., knowing a wall’s color and material, and not just its defining geometry) to further inform the range of affordances available to be detected. Enabling Dragonfly to recognize dynamic objects, such as other agents, as affordance-possibilities (either positive or negative) could lead to new insights on the interaction of mid-to-high density crowds with architectural layouts. Trends in game design, such as live physics engines, suggest that embedding our implementation of affordance-possibilities could alleviate the need to predetermine user-agent, or agent-agent, interaction. All this is to say, the application of the affordance-based control of perceptually-guided action to digital architectural design provides a promising new framework for modeling the relationship between environments and occupants, with respect to the form, function and behavioral meaning of geometrically constructed layouts. It is our hope that this approach will open new vistas for research and the possibility of fruitful interdisciplinary collaboration in the future.
References


