COMMENTARY

Neuroscience for architecture: The evolving science of perceptual meaning

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> Besides its traditional reliance on the tacit knowledge of timeless practices of construction, architecture relies largely on theories and findings of other areas of research and knowledge, instead of possessing an independent theoretical foundation of its own. During the past decades, architecture has been viewed from various theoretical perspectives, provided by, for instance, psychology, psychoanalysis, structural linguistics and anthropology as well as deconstructionist and phenomenological philosophies, just to name a few.
>
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Today this sweeping array of theories and perspectives is being expanded again by the disciplines allied under the loosely defined umbrella of neuroscience (2–4). Several families of concepts, paradigms, and methods from the neurosciences appear to be perfectly suitable for investigating what the architect would call the "human response to the built environment." These overlapping families include systems neuroscience and affective neuroscience, sensorimotor psychophysics and experimental phenomenology, to mention only some of the contenders. It is far from clear, however, which ideas will stick and what shape they will take in the new context. Just as it has happened to many prior imports to architecture, hard-won scientific knowledge may remain a foreign entity within the living body of architecture, supplying occasional metaphor and inspiring freewheeling speculation. Or the sciences may retain their natal rigor and invigorate architectural theory and practice by helping architects to test some old ideas and possibly rid their discipline of unbuttoned preconceptions, some of which had already been subjected to incisive analytical scrutiny (5–7). Against this background of uncertainty and cautious optimism, the new study of architectural affordances by Djebbara et al. (8) is interesting not only because of its scientific merits but also because of the choice of theory and vocabulary it brings with it.

Djebbara et al. (8) had human participants walking freely while immersed in a virtual environment. A wearable "brain/body imaging setup" included a 64-channel electroencephalographic (EEG) cap that allowed researchers to record the participants' electrical activity of the brain. The experiment consisted of a series of trials in which participants confronted simulated doors of different widths: Narrow (0.2 m wide), medium (1 m), and wide (1.5 m). At the onset of every trial, the participant was shown 1 of the 3 doors for several seconds. Then the wall framing the door changed its color: To green, prompting the person to pass through the door (the Go condition), or to red, indicating that the person should not approach the door (NoGo). A key result from the analysis of the participants' brain activity came from the temporal window that just followed the Go/NoGo signal. On average, the part of the brain responsible for processing visual information functioned differently in the Go and NoGo conditions. In the Go condition, brain activity depended significantly on whether the door was passable or not, but in the NoGo condition, no such difference was found.

The authors explain this result by evoking the familiar concept of affordance, introduced by the influential American psychologist James J. Gibson in 1966 (9). Gibson coined the term "affordance" to designate action opportunities offered by objects, trying to find a substitute to the term "value" which he worried would carry "an old burden of philosophical meaning" (ref. 9, p. 285). Gibson held that affordances meant "something that refers to both the environment and the animal in a way that no existing term [had done]," implying that the person and the environment are "complementary" (ref. 10, p. 127). In other words, we perceive the world not as an observer-independent reality but in the mold of potential actions, shaped by the current needs and other personal attributes of the actor–perceiver. Today the term affordance is used broadly to describe action-related meanings of objects, useful in particular because the term is sensitive to the

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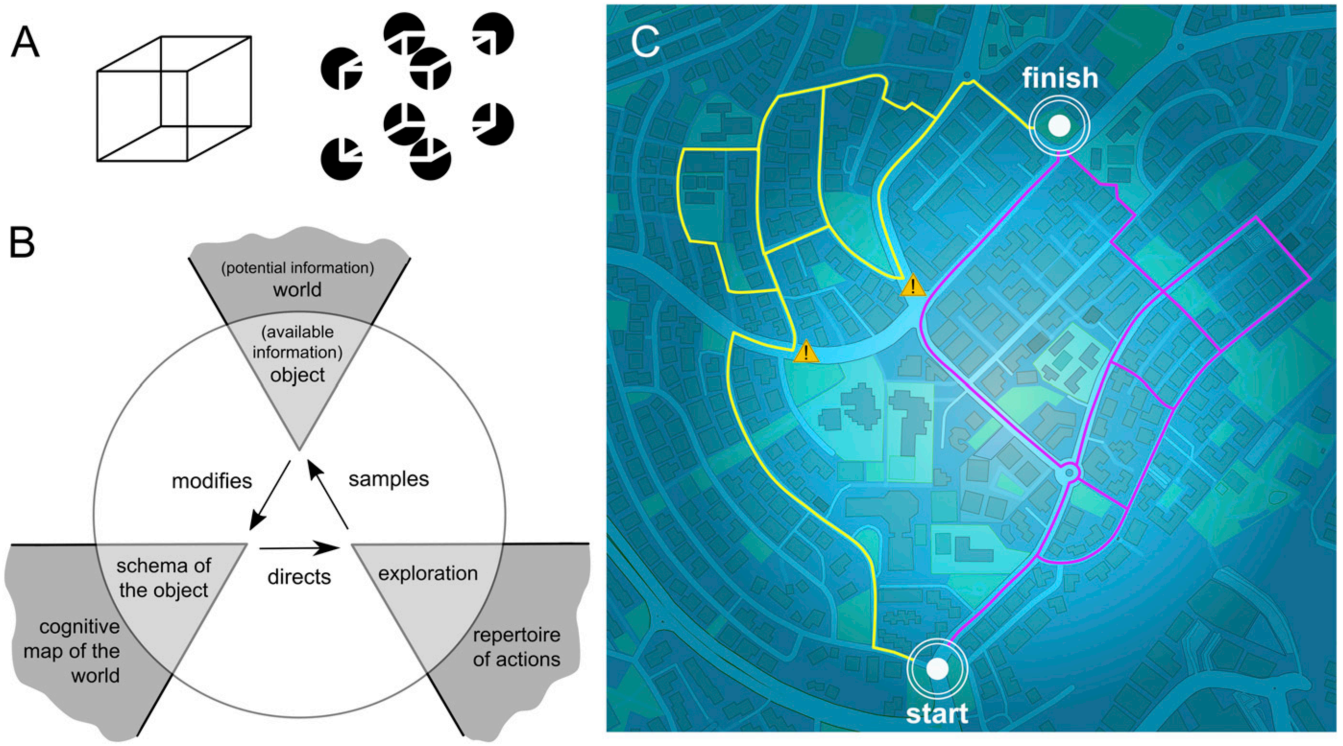

Fig. 1. **Three conceptions of perceptual meaning. (*A*) The meaning of images. Each image of the Necker cube has more than one potential meaning; it can be perceived as a cube viewed from above or viewed from below. (*B*) The meaning of objects. The object is perceived according to the observer's intended action. Data from ref. 18. (*C*) The meaning of spatial environments. Suppose you need to reach destination "finish" from location "start" in a neighborhood that you know well. Aware that one of the roads is blocked (marked by 2 warning signs), you imagine the possibilities of navigating the neighborhood if you first move left (the yellow set of paths) or right (the purple set).**

context since the same object can have different uses in different contexts.

Djebbara et al. (8) interpret their results accordingly, suggesting that "potential actions afforded by an environment influence perception." The authors also evaluate the participants' subjective state using a self-assessment manikin questionnaire. These data reveal how participants' attitude toward the doors of different sizes changed as participants learned whether the doors were passable. It was, however, the electrophysiological recording of brain activity that delivered a crucial insight. First, in the part of the brain responsible for the initial ("early") analysis of visual information, neural activity depended on whether the door was perceived as passable or not. Second, this dependency was found only when the person knew that he or she would need to act. These results suggest, in accord with the concept of affordance, that participants saw the door differently, depending on its affordance and on the broader context of action. In other words, results of Djebbara et al. (8) support the view that the world of perception is shaped by the possibilities of imminent action.

To appreciate the broader significance of this work, let us recall that the notion of affordance was one step in a long quest toward understanding how meaning arises in perception. To retrace key developments in this quest, it is useful to divide it into 3 phases.

In the first phase, the question of perceptual meaning was investigated in the early 20th century by Gestalt psychologists: A small cohort of scientific revolutionaries inspired by what was a new approach to investigating perception called phenomenology (11). Gestaltists favored "multistable" figures (Fig. 1*A*): Invariant physical objects experienced as 2 or more stable percepts. This experience is remarkable in that each stable percept is commanding; a person experiences one interpretation as the only reality he or she confronts within the moment. The spontaneous switch of perception is typically experienced as a reorganization of the larger visual field, as in Fig. 1*A*. This is why studies of multistable figures were the mainstay of Gestalt psychologists interested in the holistic aspects of perception (12). Their work helped to shift attention of researchers from focusing on the hypothetical "atoms" of perception to the actual perceptual experience: A molar process sensitive to the broader context of behavior (13). Gestalt psychology led to important methodological repercussions, urging researchers to abandon the navel-gazing method of introspection and turn to investigating brain dynamics, by behavioral and physiological means (14, 15). Indeed, it is a dynamic process in the brain that must be responsible for the changing interpretation of the unchanging stimulus, even as crude methods of the day would not capture the finer detail of brain dynamics described by Djebbara et al. (8).

In the second phase, the plethora of new phenomena discovered by the Gestaltists and their theoretical focus precipitated the development of cognitive psychology and then of cognitive neuroscience. A founding figure in this "cognitive revolution" (16) was Ulric Neisser, the author of a seminal textbook on cognitive psychology (17) who later embraced ideas of Gibson, including the notion of affordance and the notion that perception should be studied in the context of active behavior (18). Neisser integrated these ideas into a framework centered on 2 concepts: The cognitive schema and the perceptual cycle. About the former, Neisser noted that "the cognitive structures crucial for vision are the anticipatory schemata that prepare the perceiver to accept certain kinds of information rather than others and thus control the activity of looking.

Because we can see only what we know how to look for, it is these schemata (together with the information that is actually available) that determine what will be perceived" (ref. 18, p. 20).

Rather than inert templates, schemata are adaptive molds shaped by 2-way interaction with the environment, an idea captured by the influential concept of the perceptual cycle. A diagram of the latter in Fig. 1*B* highlights the fundamental notion that active exploration of the environment is indispensable for constructing perceptual meaning. Results of Djebbara et al. (8) provide evidence for this conception of perceptual meaning, following several decades of painstaking developments in acquisition and analysis of EEG data (to measure brain activity in a moving person) and in technology of immersive simulation (to present a convincing illusion of reality) (19).

The third phase was instigated by the rise of computational neuroscience, which adopted concepts and methods of analysis from such disciplines as cybernetics, control theory, and informational theory (20). Mathematical models of perception and action uncovered new dimensions of the recursive interaction between the person and the environment (21). These studies led to the realization that active organisms must continuously model potential outcomes of the intended action. Djebbara et al. (8) refer to some of this work, including the groundbreaking studies by Karl J. Friston and his colleagues. To the benefit of the emerging nexus of neuroscience and architecture, these developments should be viewed as an effort to understand the pervasive role of spatial imagination and narrativity in active human behavior. Imagining the future is a necessary part of making sequential decisions. The nervous system of the active perceiver incessantly evaluates and selects among alternative futures. Just as we imagine potential obstacles on our daily commute (Fig. 1*C*), the multipronged imagination required for active behavior has a limited depth of computation (22, 23). The number of possibilities in every scenario rises rapidly with the depth of computation, requiring greater neural resources and turning this problem into an economic challenge (24). Despite the computational jargon in which such problems are couched, it is important to remember that every potential scenario follows a familiar narrative course: Preceding events constrain subsequent events much like having a loaded gun on the stage is a prerequisite for the gun to go off in the third act of a Chekhov play (25).

The study of Djebbara et al. (8) is evidence that neuroscientific methods have evolved to a degree of sophistication that allows researchers to test hypotheses about perception and action in realistically complex environments. Beyond investigating landscapes of available actions, we stand on the threshold of probing such elusive notions as the meaning of narrative. Applications of these capabilities stretch from numerous architectural specialties, such as urban design, landscape architecture, and wayfinding, to other "spatial professions" that include design of immersive video games and spherical cinema.

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