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Meaning in Architecture: Affordances, Atmosphere and Mood

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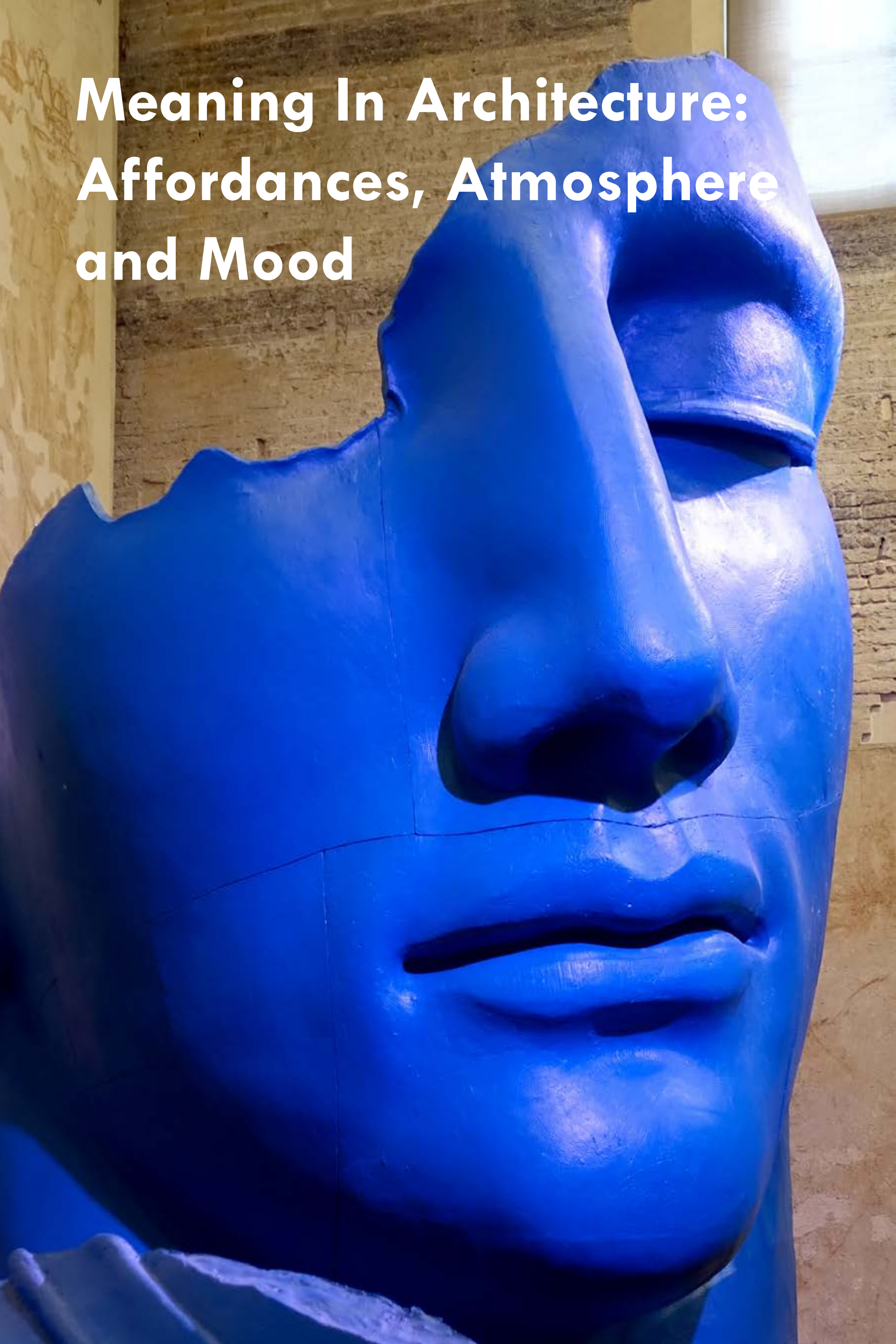
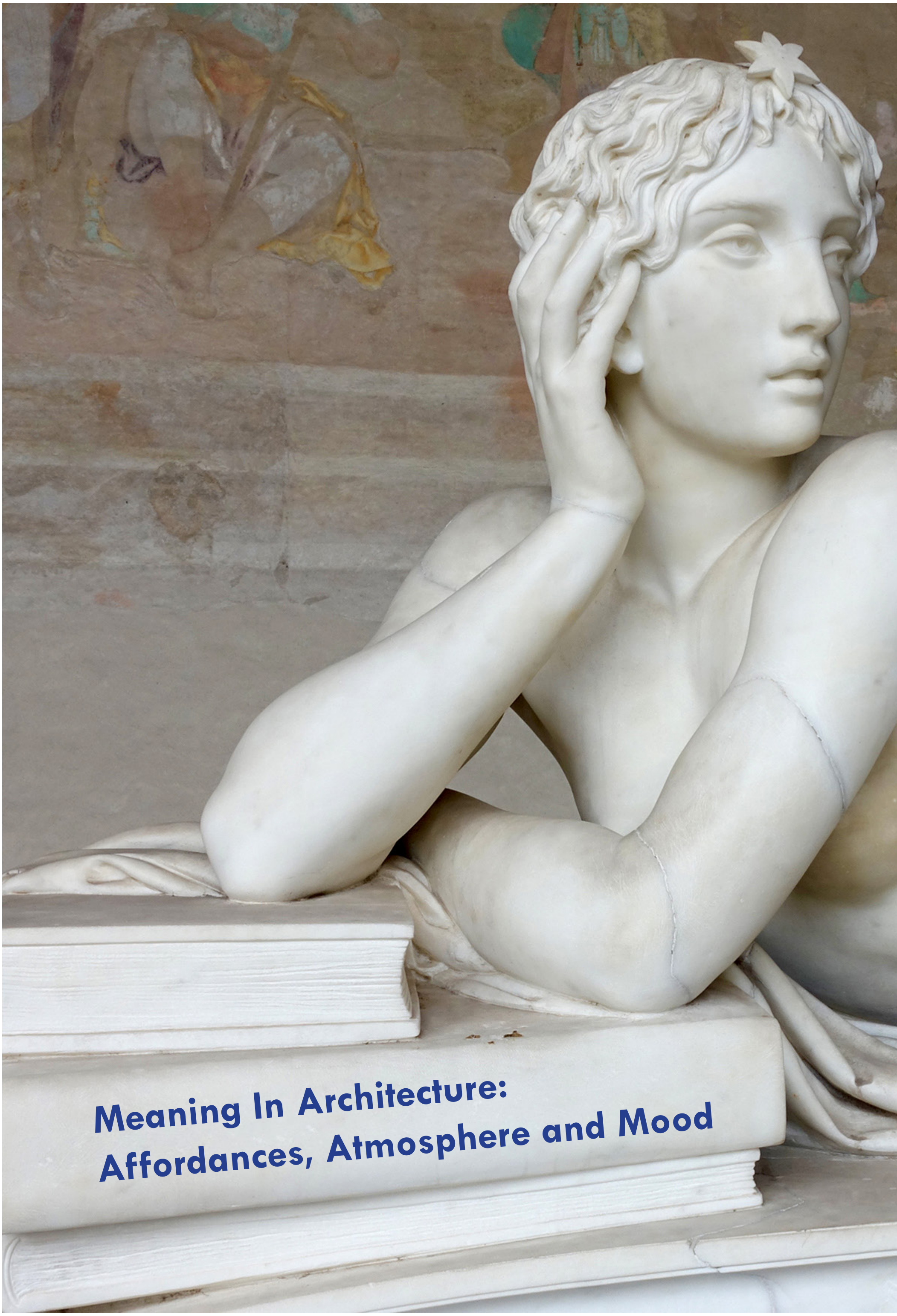
By understanding the limits of neurocognitive processing, we come to know the finer details which describe the parameters from which we live in, and create, the world. Dr. Kevin Rooney.

Meaning in Architecture: Affordances, Atmosphere and Mood, reports on a 2018 forum about human awareness and buildings, specifically speaking to the significance of affordances, embodied simulation theory, atmosphere and mood. This exchange between scientists and architects was the inaugural ANFA/Interfaces discussing the intersection of brain function, as studied by neuroscientists, and our built environment, an expertise of architects. Architecture and the biology of perception are a collective pursuit to discover the physiological framework when confronted with our natural and built environment. Speaking to our body, brain, and environments agenda, Dr. Michael Arbib, in "The Architecture-Neuroscience Conversation and the Action-Perception Cycle," argues there is more to understanding space than just the hippocampus. With "Place, Peripheral Vision, and Space Perception: a pilot study in VR." Dr. Colin Ellard and Robert Condia demonstrate the split and consequences of our peripheral and central vision through measured responses in VR of 2 urban squares. Similarly, Dr. Brent Chamberlain's "The Physio-Affective Built Environment" explores the exchange of the body and space in a direct application to one's urban environment.

Architecture is something that we as humans do, to ease our living conditions, and as such, it should reflect what humans are and needs . . .. Neuroscience for architecture is a new and emerging field. It is therefore a welcome sign of maturation, that concepts that has proven to be meaningful for architects though still somehow vague in their meaning in terms of architecture like affordances, atmosphere and mood, is now attempted to be addressed through this new and powerful source for knowledge. While the breach might not yet be perfectly closed, Meaning in Architecture: Affordances, Atmosphere and Mood is one important step. Dr. Lars Brorson Fich.

Meaning In Architecture: Affordances, Atmosphere and Mood





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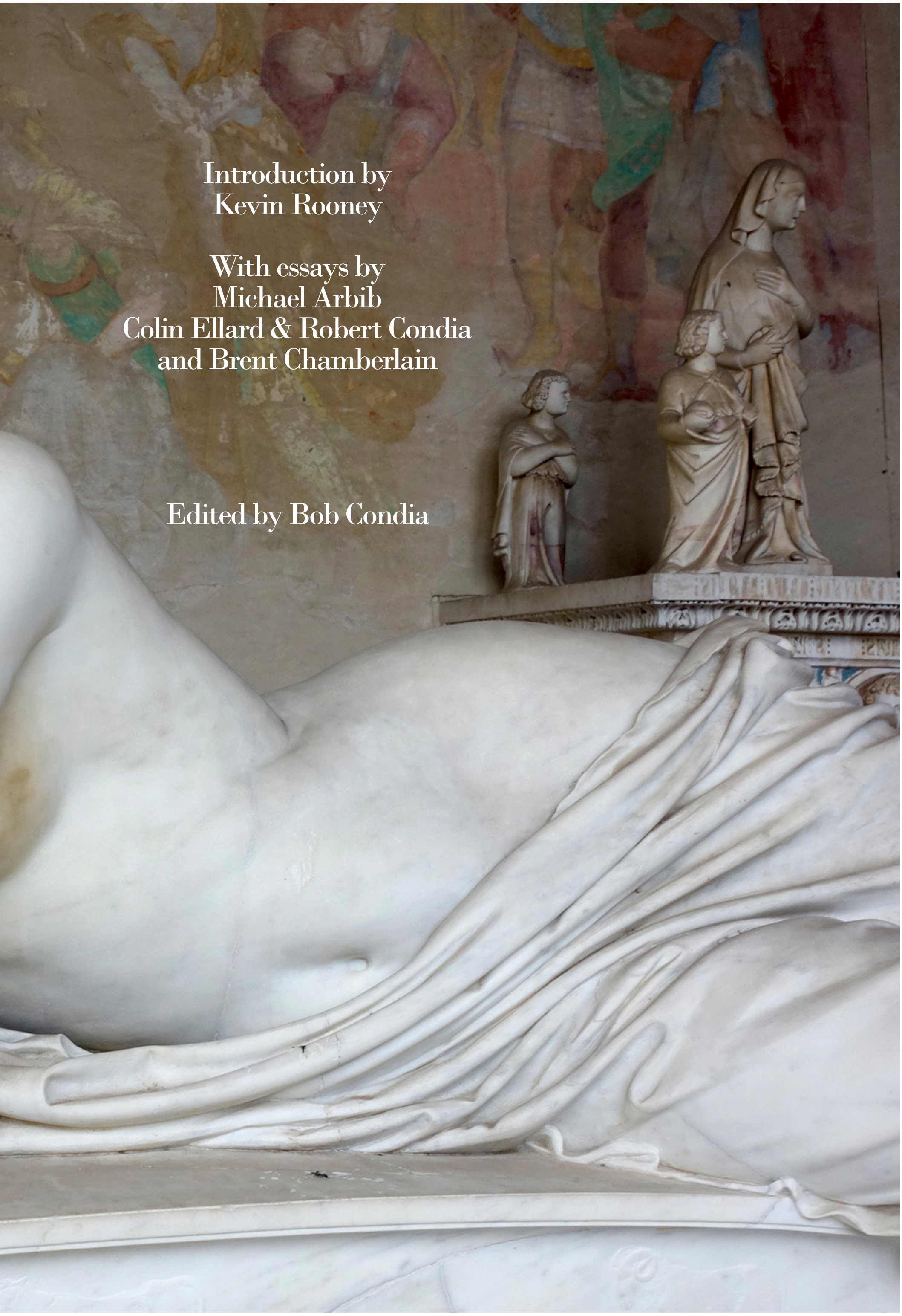

Introduction by
Kevin Rooney

With essays by
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Colin Ellard & Robert Condia
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Dr. Kevin Rooney

Introduction

Figure 0.1 Cooper Union. 41 Cooper Square, Thom Mayne and Morphosis (2006-2009). A feeling of harmony or dissonace?
https://commons.wikimedia.org/wiki/File:Cooper_Union_New_Academic_Building_from_north.jpg

What benefit, if any, is there to gain by combining the efforts of architecture and neuroscience? The former profession lays claim to thousands of years of physically manifesting civilization, while the latter, whose own enlightenment is taking shape, has greatly expanded our conceptualization of how our minds operate. Did the ancient Greeks suffer from a lack of neuroscientific knowledge when building the Parthenon? Did early neuroscientist need to know about architecture in order to discover the relationship between lesions and motor activity? No. Although that answer is true, it seems to remove a very common element amongst both professions. The element of environments. Regardless of your position as an architect, a neuroscientist or as a lay philosopher, humans live in the world and that world is predominantly built by humans. Any study of neuroscience inevitably must ground its findings in our world if it is to say anything useful, and any built architecture must come forth through the use of imagination held together by the neurons firing across regions in the brain.

When occupying built environments people are confronted by a complexity of decisions and emotions all processing in the framework of our mind. The spaces we build are designed, good or bad, to accept our inhabitance and therefore accept the neurophysiological condition our inhabitation longs for. In this relationship between design and inhabitance, we can see the unfolding of our inner desires to change the natural world into our world in which our emotions search for fulfillment. Homes to raise families and invite guests. Churches to gather and worship. Plazas to unite in the pursuit of culture. Universities to guide our attention toward education. Underpinning each of these is a longing to connect in a type of free contract of engagement. A longing to find some part of ourselves in those around us and, in that longing, gain some part of them in the exchange. In pursuit of these connections, success is measured by creating harmonious environments while our failures are measured in the feeling of dissonance (Figure 0.1).

By explaining the relationship between design and our desires to inhabit, the aim is to illustrate a reciprocal nature of built environments and its inhabitants. Each one feeding the other; our desire to connect through our choice of inhabitance and our desire to design appropriate habitations. In the center of this cycle resides a common neurophysiological network that both manifest the desire and provides the framework that makes it possible for us to live within the world. Our skin micro sweats when we are aroused by a grand space. Our face sends small electrical impulses to our face to smile when immersed in the soft glow of our favorite romantic restaurant. Our hippocampus aids in allowing us to navigate buildings visited for the first time. The ventral and dorsal stream of our brains allow to coordinate the "what" and the "where" of our environment respectively. Through technology and experimental consideration we can now explore this complicated process that not only reacts but transforms the environment around us.

Returning to the first question, what is there to be gained? Dr. Michael Arbib, Professor Bob Condia, FAIA, Dr. Colin Ellard and Dr. Brent Chamberlin provide points of reference from where others may join in articulating the answer. Arbib's description of how our minds map environments, Condia and Ellard's experimental extension of Rooney, Condia and Loschky's (2017) focal and ambient processing of built environments hypothesis, and Chamberlain's physiological investigation into the affect of navigating environments, all provide nodes of exploration from which to critique the relationship between neuroscience and architecture (Figure 0.2). Like the Greeks correcting the appearance of the column through entasis and fluting, the work herein is an assessment willing to stand back and question the current structures we rely on.

So herewith we initiate this inquiry: What bridge, if any, combines the struggles of making buildings with the biology of people? If our environments are the middle ground – as we suspect – then irrespective of your position as an architect, or neuroscientist our next step inevitably grounds itself in the real world brought to our imagination by the electro-chemicals firing in the brain.

Figure 0.2 Taubman Museum, Roanoke. Randall Stout ArchtiectS (2008). What do forms and surfaces today have to say about our engagement with buildings? https://www.azahner.com/works/taubman

Michael Arbib

The Architecture-Neuroscience Conversation/the Action-Perception Cycle

Figure 1.0 "Servi Multi," Roberto Barni, 1988, Bronze at Fattoria di Celle, The Gori Collection near Pistoia, Italy. How do we see, feel, touch, taste, smell, hear ourselves in spaces we build?
Image by Bob Condia (2015)

I offer the slogan "Ask not only what neuroscience can do for architecture, ask what architecture can do for neuroscience," with apologies to John F. Kennedy and his Inaugural Address as US President on January 20,1961. The first concern is with bringing neuroscience to architects, both to provide an enriched understanding of how we experience and design buildings and (though not here) to offer ways in which studies in cognitive (neuro)science might enrich evidence-based design for different typologies based on knowledge of the different brains of, say, young children and people with Alzheimer's disease. The second concern is to develop new hypotheses for brain research, facing the challenges of leaving the-well defined confines of a lab where a few well-controlled variables to opening one's self to address behavior and experience in the built environment, whether people are interacting the outside the inside of buildings.

My point is that neuroscience is not a static pool of facts to be plugged in to solve architectural problems. Rather, I want to explore the claim that architecture can offer challenges that call for new research in neuroscience. Continued conversation can then expand both the neuroscience insights and their application to architecture – both in solving specific problems (cf. evidence-based design) and in enriching our understanding of very basis of architecture as a human practice (cf. philosophy).

For today, I want to offer conceptual insight into how hippocampus functions – not on its own, but as one system within a system of systems.

This paper seeks to convey some ideas of "how the brain works" in the hope that this can deepen the conversation between neuroscience and architecture by moving beyond the mere generalities about the brain that often occur in this conversation. The talk by Condia and Ellard also moves us in this direction by telling us more about the visual system, distinguishing central from peripheral vision, and introducing the contrasting roles of the dorsal and ventral streams from primary visual cortex to other key regions of the cerebrum.

Although the hippocampus will play a key role in this paper, we want to understand its role within the brains of people moving through buildings or moving around buildings or doing things inside buildings.

We thus need to consider not just multisensory perception -- how we see, feel, hear, touch, smell, and taste the building – but also how we act in relation to the building (Figure 1.0). The classic diagram of what we call the action-perception cycle (Figure 1.1) goes back to Ulric Neisser (1976), then a cognitive psychologist from Cornell.

Let's consider the three triangles in turn:

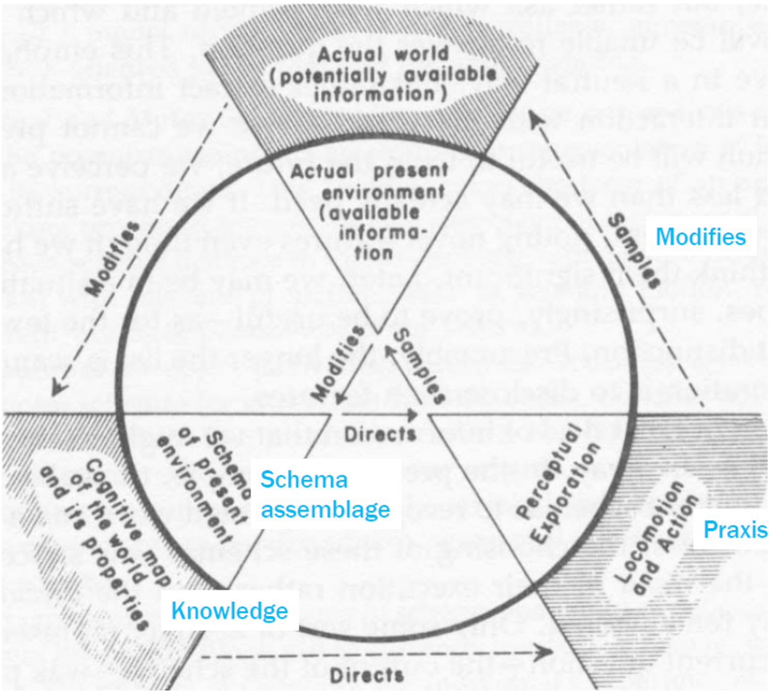


Figure 1.1: The Action-Perception Cycle. I use slightly different terminology from Neisser's. Where Neisser speaks of "schema of present environment" I use "schema assemblage of present environment"; and where Neisser speaks of the "Cognitive map of the world and its properties," I will speak of "Knowledge of the world and its properties," reserving "cognitive map" for knowledge of properties of the world of specific relevance to navigation. See the text for description of the three triangles. (Adapted from (Neisser, 1976): Cognition and Reality: Principles and Implications of Cognitive Psychology.)

Top: Out there is the "actual" world, but at any time there is only a small part of it, the "available information," that we could possibly sample, due both to our spatial relationships with the external world and to the types of sensors we possess.

Left: At any time we have built up what Neisser call a cognitive map, but it is in a somewhat different sense than that emphasized below, and so I will speak of our knowledge (or long term memory, LTM) of the world and its properties, which may be tacit or explicit. Again, where Neisser talks of the schema of the present environment, I will talk of the schema assemblage, stressing the role of multiple schemas as we construct our perception of the environment (in some sense building a working memory, WM). Input from the top triangle may modify both our knowledge of the world and our sense of the current environment.

Right: The division here is between two types of action, but each guided by our knowledge of the world in general and our understanding of the current environment. "Inner" actions include eye movements or running our hand over an object, each intended to extend our sampling of the world around. Locomotion may also serve this purpose of aiding perception, but actions also allow us to change the world, not just sample it, even in as simple an act as cutting a slice of bread. And, of course, the world itself is continually changing without need of our intervention, and that world includes other people so that action may include social interaction which may involve conversations which can change both our knowledge and our current views.

Our brains are always active and what we do and what we perceive depends not only on our conscious mental and emotional state and our relation to the current environment, but also on a range of neural variables that are below consciousness and yet which may (but may not) affect our later experince and behavior.

To summarize with a little bit of jargon, the crucial idea is the internal state. As we move, we change our relation to the environment. We change our mental state, which changes the way we will explore the environment and the way we will act in the environment. The way we behave depends on the current relationship with the world, but also on many variables that are hidden from view. What are you thinking about? What are your motivations? What are your needs? What memories come to mind? What is your cognitive map?

Introducing the Hippocampus

The notion of a cognitive map is familiar to most of us, though I will analyze this notion more fully, but I have to tell you about the hippocampus, and then I have to tell you why knowing about the hippocampus is both a good thing, but not enough. The hippocampus is of great relevance to wayfinding and to episodic memory.

Perhaps the best-known story about the hippocampus is about this poor guy, HM, who had such bad epilepsy that his surgeon, Scoville, cut out a huge part of his brain, including his hippocampus (Figure 1.2). This cured the epilepsy, but had a terrible side effect. HM could not form new episodic memories (Scoville & Milner, 1957). If you talked to him for a few minutes, he seemed quite normal (his "working memory" was fine). But leave the room, come back a minute later, it was as if he had never seen you before. Very disconcerting.

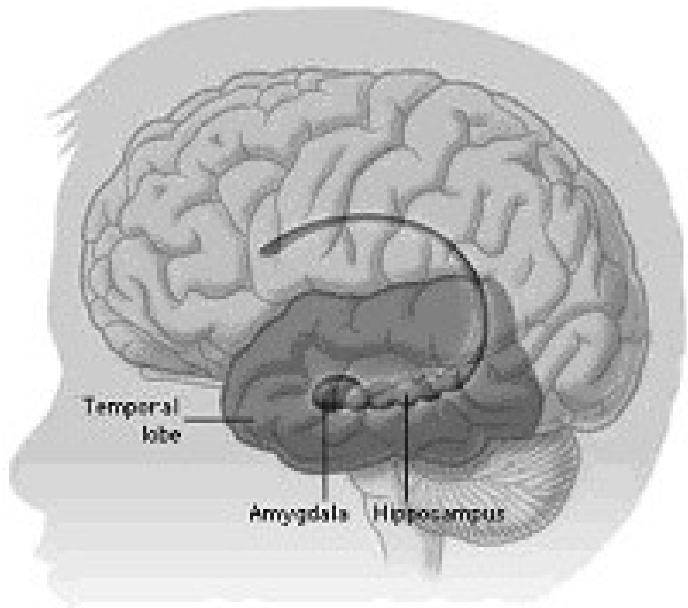
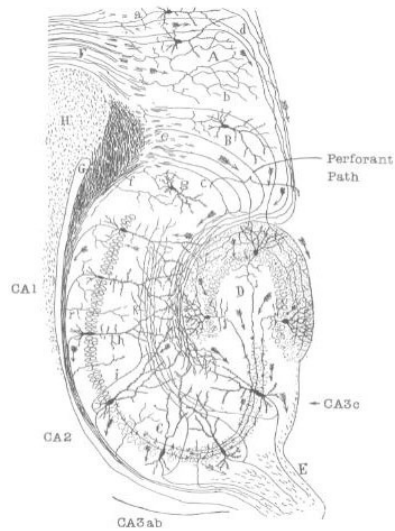


Figure 1.2: A sketch of the human brain in cross-section, showing the extent of the region removed from HM's brain during surgery. The hippocampus is only one part of the area removed, but subsequent research has demonstrated the key role of the hippocampus in forming memories of episodes. However, over time memories may be consolidated in cerebral cortex, and so HM maintained a range of memories of his life before the surgery.

But what I want to concentrate on here is the relevance of the hippocampus to cognitive maps. Back in 1971, John O'Keefe and Jonathan Dostrovsky (1971) discovered what are called place cells in the hippocampus of the navigating rat. Figure 1.3 shows a cross section of the hippocampus. Hippocampus is the Latin for seahorse, and if you are imaginative, you can see the shape of the seahorse in that cross section. Recording from single cells, and trying to see what it was that correlated with its activity, O'Keefe and Dostrovsky found cells that seemed to respond best when the rat was in a particular part of its environment, its "place field" (Figure 1.4.)

The idea that the hippocampus can tell you where you are has been a touchstone for many people thinking about way finding and other problems. In fact, back in 1978, John O'Keefe and Lynn Nadel published their classic book, The Hippocampus as a Cognitive Map (O'Keefe & Nadel, 1978). What I want to do here is think through the idea of a cognitive map and suggest That the hippocampus can support a cognitive map through its interaction with many different brain regions.

Why should architects care about this? I will not offer any specific applications of this knowledge here, but the suggestion is that if we really want to understand how people interact with the world – or,



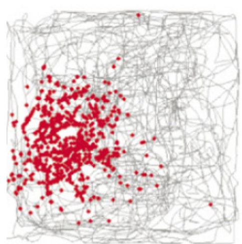


Figure 1.3: (left) A cross-section of rat hippocampus drawn by the great Spanish neuroanatomist Santiago Ramon y Cajal, showing the shapes of typical neurons and the major pathways (bundles of axons, output lines, of neurons) linking different subregions.

Figure 1.4: (right) The black tracery records the trajectory of a rat moving around this square enclosure. The red dots show where a single neuron recorded by the experimenter fires vigorously. Since they cluster in just one part of the enclosure, this neuron is called a "place cell" and the region where the rat must be for it to fire is called its "place field."

for architects, the built environment -- the phenomenology from introspection is not enough. We need to know what different parts of the brain are doing, and then, perhaps, we can develop new design approaches that can differentially tap in to different aspects of brain function. That's the dream, but not what I can yet deliver.

Defining Cognitive Maps and Affordances

A classic cartoon shows a man lost in the Arctic waste. He discovers a billboard, but finds it contains only an X with the legend "You are here." Poor fellow. For a map to be of any use to him, it must help him get where he wants to go. My perhaps unkind parody of hippocampus is that it is not a map because it just says you are here. Now, I have to confess, there has been a lot more research on the hippocampus since the brain model described above was developed. Indeed, there is a monthly peer-reviewed scientific journal called Hippocampus established in 1991 (Volume 28 in 2018) which documents research on the neurobiology of the hippocampal formation and related structures. There may be hidden treasures there that greatly enrich the relevance of the hippocampus and cognitive maps to architecture but that is a story for another day.

What does it take to build a "real" map? Consider the classic map (Figure 1.5) of the Underground, the Tube, in London. To use this map, you have to find the station name X for where you are, and the station name Y for where you want to be. You then try to find a path from X to Y on the map which you then decode to tell you which lines to take and where to change trains to get to your desired destination. This is an excellent map but it is not a cognitive map because your brain has to work hard to find that path. My suggestion is that, by contrast, a cognitive map is the whole system in the brain that allows an animal – or you, without looking at a paper map or consulting your smart phone -- to find its way to a destination in a known territory. Let me get formal for a moment. First note that the map of London (Figure 6) has limited coverage, restricted to the Tube stations of London and the connections between them – it covers only a limited aspect of some "territory" limited both as to region and as to the features that are included. Secondly, it requires a certain skill to use it. For people new to subway maps, much explanation will be needed before they can use it effectively. With this, we can define the sort of map exemplified in Figure 5, or on a page of an atlas.

Definition: An "ordinary" map M for a user U is a representation of a limited "sample" of space S such that:

1) U can find in M a representation M(A) of U's current location A
2) U can find in M a representation M(B) of U's desired location B
3) U can find a path in M, PM(A,B), from M(A) to M(B)
4) U can transform PM(A,B) into a path in S, PS(A,B), from A-B

Figure 1.5: A classic map of the London Underground.

This makes explicit the limited coverage of such a map, and the fact that it requires some ability to use it to navigate.

> *Definition:* A cognitive map is a system that combines an "ordinary" map with cognitive mechanisms that support the capabilities (1)-(4).

Consider searching for a restaurant in a new town. One approach (Locale) is to ask the concierge at your hotel for a recommendation together with a paper map on which is marked a route that you can follow. Alternatively (Taxon), you could just wander around town until you see signs that you recognize as marking the entry to a restaurant. More formally, O'Keefe and Nadel (1978) distinguished between two paradigms for navigation:

Definition: Two systems for navigation:

- *The locale system for map-based navigation proposed to reside in the hippocampus (and which we will locate in a set of interacting brain regions, of which the hippocampus is just one)*
- *The taxon (behavioral orientation) system for route navigation based on egocentric spatial information (which we view as based on affordances).*

The word taxon may be unfamiliar, but it is cognate with the word taxis – not in the sense of cars and drivers for hire but as used in phototaxis, going towards the light, or phonotaxis, going toward the sound. In the example, we might (but would probably rather not) speak of restaurantotaxis. What then is an affordance? It is an invitation to/indication for action. The key notion due to J.J. Gibson (1966, 1979) is that visual perception can signal to us not only what objects are in the current scene, but what possibilities for action are available. When we discuss navigation, our focus is on affordances for locomotion, but my colleagues and I have also considered affordances for hand movements as well (Arbib, 1997; Fagg & Arbib, 1998). In the case of the restaurant sign, the affordance is indeed part of our conscious ability to categorize the objects around us, but Gibson stressed that many affordances can affect our behavior even in the absence of conscious recognition. When walking down a street, for example, you may suddenly jump to the side – not for any conscious reason but because your peripheral vision detected an imminent collision and made you detour to avoid it. And this need involve no conscious awareness of who or what you have just avoided.

Architectural Example: An Art Gallery

Consider your navigation when you visit an art gallery for the first time. At first, you don't have a cognitive map specific to the museum. That's important. We are not only interested in a cognitive map as something you have, but as something you construct through your experience. As you explore the gallery, you build up a cognitive map. You might decide that you first want to go to the exhibit of pre-Columbian art. For that, you might get directions (locale system), or you could just explore at random until you recognize some exemplary artefacts (taxon system). Here we have a whole set of challenges about what sort of knowledge one has for wayfinding if one already knows a complex environment like an art gallery versus if one is new to the gallery. And this in turn raises consideration about what the architect does to assist people find their way in a new building.

What about within a particular room? The normal experience when you enter a room in an art gallery is that there might be a statue or two, a bench, or a couple of display cases in the center, but most of the paintings or other exhibits will be around the walls. When you come into the room, maybe you will turn and read a description on the wall, and then go left or the right, following the wall until you've explored enough of the room. But if you are there to locate a particular artwork, some of the pieces won't interest you. You'll walk by.

For others, you'll stop. You develop a strategy for viewing them. You approach and choose a viewing point. You contemplate the object. Meanwhile, you have been avoiding obstacles, benches, other people, and choosing how to proceed.

What is interesting is that even before you visit the museum, you have what may be called an "art gallery script" or "frame" (Minsky, 1975; Schank & Abelson, 1977). You have a general idea of the way art galleries are laid out. There are going to be various rooms. You try to find the room that has the exhibit of interest to you. Then you probably expect to turn and look at the wall to see a description of what's in that room, and then follow the walls, deciding which pieces to stop and look at. All these involves affordances and navigation that complement whatever cognitive map you may already have, but at the same time contribute to building up the cognitive map. You come to know how some of the rooms are related to each other, and how to get back to the entrance.

With this, let's look at Sao Paulo Art Museum (Figure 1.6). It was designed by Lina Bo Bardi who was born in Italy, but did most of her work in Brazil. From the outside, it is already interesting as a very unconventional piece of architecture, built like a suspension bridge.

As we approach from the street, our first job is to get safely across the road, and then to get into the building. One might expect that for a building of this type and size, there is going to be a magnificent entryway, and architectural features that focusing your attention on how to get to that entryway. But Bo Bardi opted for the idea of a public space on the ground level where people can gather for meetings or demonstrations or other social activity. It requires some visual exploration to discover

Figure 1.6: São Paulo Museum of Art, designed by Lina Bo Bardi. (The structure at far right is another building.) My photo shows the challenge of crossing the street.

at "affordances for entry," afforded by a staircase and an elevator. Once you have chosen how to enter and reached the exhibit hall you discover that Bo Bardi had a very unusual idea about how to exhibit the art. For the first few years of the museum, the curators followed her method but then decided it was too radical and divided the space up rather conventionally. Recently, however, they mounted an exhibition following her standards. Instead of hanging paintings on the walls, each painting is affixed to a big sheet of glass held vertical by being rooted in concrete blocks (Figure 1.7). Instead of following a wall to find artworks, you stand in front of one exhibit, then you look around to catch glimpses of others. Based more, perhaps, on an aesthetic rather than a wall following criterion, you decide where to go next, with affordances helping you follow a path that avoids obstacles. Bo Bardi transformed a systematic exploration one linear subspace at a time (the art on a wall) to a much more varied exploration of artworks distributed

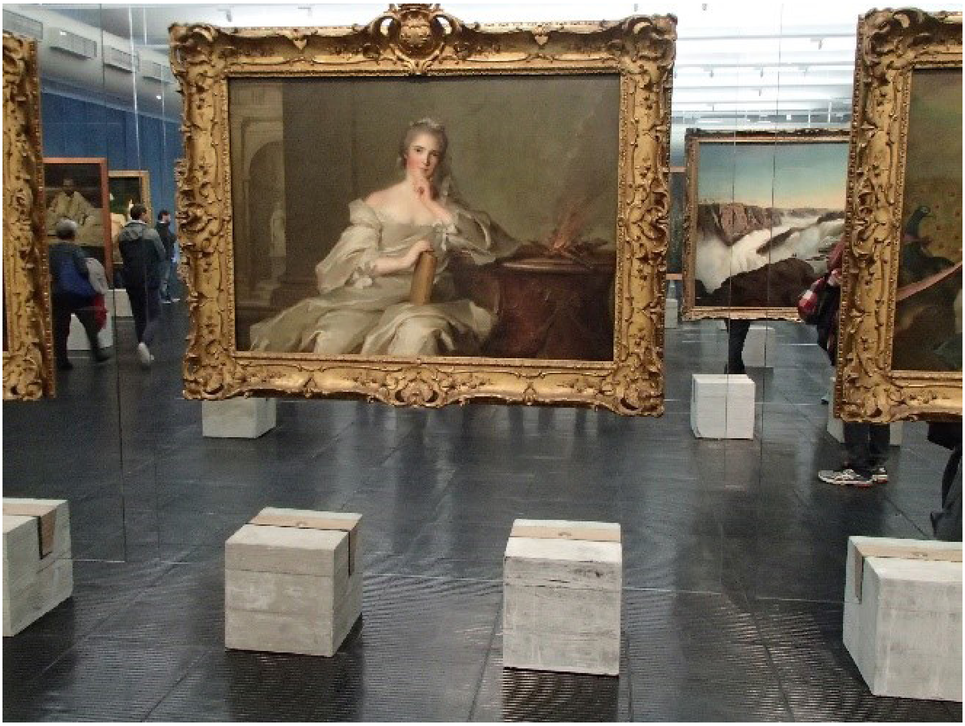


Figure 1.7: The unusual way of mounting paintings designed by Bo Bardi.

across the 2D space of the open floor (the only walls are external, where the windows are, with no art displayed).

The point of discussing this particular Museum is to make clear that architecture may both build on conventions and defy them. In the first instance, getting into the place, Bo Bardi is defying one convention, namely a magnificent entryway for an important building, but on the other hand, she makes it easy for you to see the stairs and elevators. In the second instance, she defies a familiar strategy for touring an exhibition and invites you to see works and their relationships in new ways. As an aside from the main thrust of this article, consider the point that interesting architecture both builds on the scripts people have for the given type of building, and yet departs from those scripts to make the building special.

A High-Level View of a Computational Model of the Brain Systems Involved in Navigation

With that, let me now probe deeper into the brain mechanisms that support the locale and taxon systems by introducing a the TAM-WG (Taxon Affordance + World Graph) model of navigation (Guazzelli, Corbacho, Bota, & Arbib, 1998). What I hope to get across is the interest (at least to the cognitive neuroscientist) in knowing in some detail what underlying brain processes are engaged in our interaction with the world (and that includes the experience and design of buildings). For example, Condia and Ellard stressed the differential roles of center versus the periphery. In vision, and explored the notion of ventral and dorsal pathways for vision in the brain. *My over-arching point here is this: to work effectively, architects must know more about the brain, and neuroscientists must know more about the experience and design of buildings.* What each must know about the other's discipline will vary from task to task – thus Condia and Ellard's focus is on aspects of vision that are not part of the TAM-WG model and, conversely, they pay no attention to the hippocampus. Further work might need to bring neuroscience aspects of both studies together to address other architectural problems. Note that I am not saying that neuroscientists and architects must each master the other's field, only that they must know enough to be able to work together. The parallel with the relation between architecture and structural engineering may be apropos. What follows, then, is missionary work, an attempt to answer the second of two key questions that must be answered to advance neuroscience-architecture collaboration. How do we get neuroscientists to understand key aspects of what the architects know? How do we get the relevant findings of neuroscience details to the point where they are no longer confusing but become part of our general understanding?

Let's take a quick look at the advance copy of Figure 1.8 (a depiction of the TAM-WG model described below). It is placed out of order here because I want you to give it a quick examination now, but with the hope that you will understand it when we meet it again. The architect may find the Figure overwhelming, and my strategy will thus be to build up to it through several pages of text and figures. But note that the floor plans for a building may equally confuse the neuroscientist – yet Bob Condia says he can simply "read" one to imagine what it would be like to walk through the building. Similarly, each of us goes beyond the words of a sentence to conjure up a meaning for it, a musician can hear the music as she reads musical notation, and a cognitive neuroscientist can see the brain working as he explores diagrams like Figure 1.8.

First note that a computer model of the brain ultimately takes the form of a computer program which provides detailed instructions for running computer simulations to test the model. (Note that for an architect, the program is the initial specification of requirements for a building; for the computer programmer, the program is the detailed set of computer instructions which will achieve the specifications.) We check whether, when we provide the simulation program with codes for the inputs to and internal states of an animal (or a subsystem under study) then the computed result will match observed data or offer unexpected results. In the latter case, we may need to update the model, or we may be able to offer new predictions to be tested by experiments (Arbib, 2016).

One might thus compare the relation between a diagram like figure 1.7 and a simulation program to that between a floor plan and a working drawing. In either case, one needs a hierarchical analysis, understanding how details contribute to higher level systems. Whether in the working drawings for a building or in a computer program for a model of the

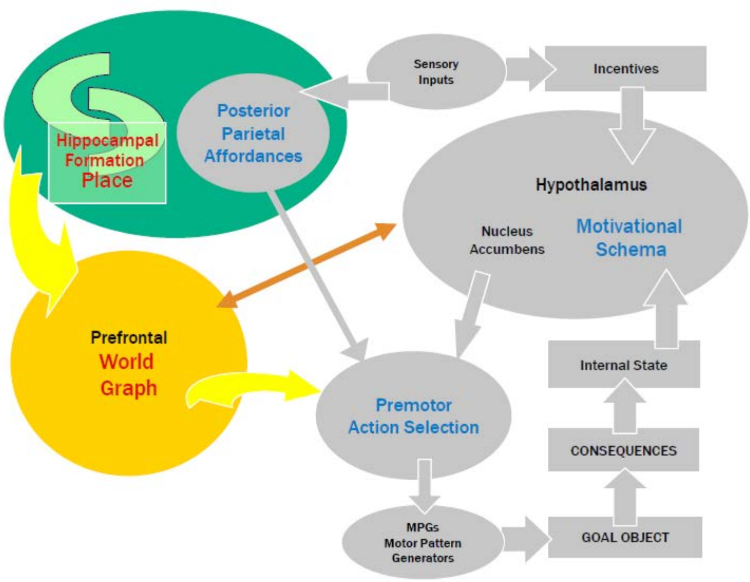


Figure 1.8: The complete TAM-WG (Taxon Affordance Model + World Graph) model. We will meet Figure 1.15 again, at its proper place in the article. Here the aim is not to explain the model (that comes later) but instead to simply note the key features of such a diagram of a brain model: There are "boxes" connected by arrows. Each box is labeled with a function; some are also labeled with the names of brain regions. The association of a function with a brain region, or the claim that an arrow represents connections between the two indicated brain regions will in general be based on available data, but in some cases will represent hypotheses which suggest new neuroscience experiments.

brain, one needs to understand how subsystems contribute to higher level systems and how they themselves may be decomposed.

Where an architect may be describing a building that is relatively static (although it will provide a stage on which people behave and interact), a computational model of the brain provides a dynamic map of a changing system that is continually reconfiguring itself, changing state, acting accordingly. A computational model (unlike most physical models of buildings) underlies a dynamic map of a changing system – e.g., more akin to a weather map than a highway map. Even if we do not see them on the screen, the weather map is based on state variables to support predictions of how the weather will change. When we develop a model like the Taxon Affordance Model + World graph model, each region:

a) corresponds to a region in the rat (or other) brain or represents a relevant function whose localization in the brain is irrelevant to the scope of the model, and

b) contains state variables and algorithms or modeled neural net dynamics for how the internal state will change as inputs come in (whether sensory inputs, or from other regions) and outputs go out (whether to control overt behavior or affect other regions).

Recall my earlier comment that neuroscientists and architects need only know enough of each other's field to be able to work together. Thus, for the architect interested in, say, the relevance of the hippocampus to wayfinding, it might be enough to understand the TAM-WG model at the level provided by the upcoming exposition offered in this paper, but without any need to master the details of neurophysiology and neuroanatomy that guided the modelers in filling in the details needed to write a computer program for simulation that meets criteria (a) and (b).

The boxes in Figure 1.8 have one or two labels: a function and/or the name of part of the brain. In this brain regions names are hippocampus, three areas of cerebral cortex (prefrontal, posterior parietal, premotor), hypothalamus, and nucleus accumbens. This is not the place for a tutorial on functional neuroanatomy. I just want to make the point that when a neuroscientist talks about the brain s/he brings to bear knowledge about various brain regions, perhaps gleaned from animal neurophysiology or human brain behavior or neurological disorders, all with respect to a certain set of behaviors. Thus, as we learn to talk to each other, architects must learn at least the basics of such data to the extent that they are relevant (and note that what is relevant will differ – just as Ellard and Condia did not need to mention hippocampus and the model here does not distinguish central from peripheral vision. Conversely, neuroscientists need to learn enough about the challenges of architecture to better understand what part of their knowledge may be relevant – or, indeed, whether new research in neuroscience is needed to develop the relevant insights.

Some boxes do not have anatomical labels. This could mean either that the relevant brain regions that support the function are not known or that the modeler can rely on (or hypothesize) the availability of the relevant processes without needing to invoke any data about the neural activity that underlies it. Because of this, Figure 1.8 can omit explicit mention of visual and other sensory areas of cerebral cortex as well as motor cortex and a range of subcortical brain regions and the spinal cord. Much of this will become clearer as we develop the model via Figures 1.5 to 1.15 below. Of course, to fully appreciate the details of the model and the data that supports it (and these may or may not be relevant to the architect), it is necessary to go back to the original article (Guazzelli et al., 1998) and, possibly, an update (Arbib & Bonaiuto, 2012).

But leaving such details aside, let's see if an incremental approach can render Figure 1.8 accessible. We first introduce the taxon affordance model (TAM), showing how we can navigate based on affordances, and then bring in the world graph model, showing how the brain can build up a cognitive map, and show how the two work together. This will take us, finally, finally to the title of the talk as we make clear that the hippocampus is not a cognitive map in and of itself, but it is a crucial part of a cognitive map. Although the model was based primarily on data on the brains and behaviors of rats, I shall use accounts of human behavior to motivate the exposition – and to better suggest its possible relevance to architects assessing the behavior of people in the built environment.

Figure 1.9 shows the stripped-down part of the model for just responding to an affordance. Sensory inputs come in. Various affordances are detected (posterior parietal cortex). (Let me reiterate: For the sake of this functional analysis, just where the named regions

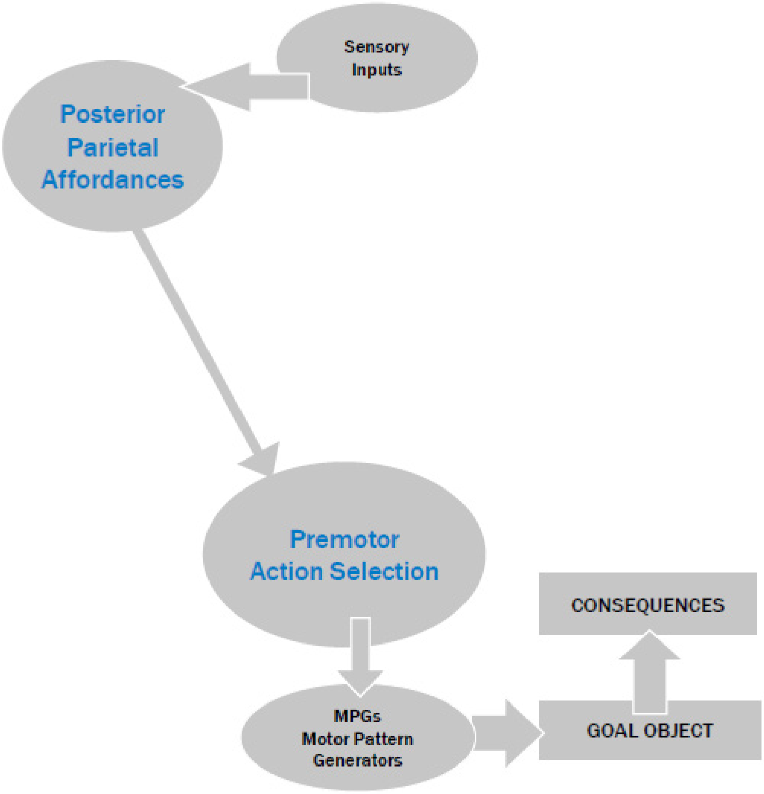


Figure 1.9: TAM (the Taxon Affordance Model) without learning.

are located in the brain is irrelevant. For the neuroscientist seeking data to support or test these claims, the location is crucial.) For the case of a walking human, affordances might be offered by a gap in the crowd, an interesting doorway or a sign that you would like to read. In this case, three affordances are competing. Which one do you locomote towards? The premotor cortex is the one in which it is established which one of those affordances you are going to act upon (other brain regions outside premotor cortex assist the decision), and this decision is relayed (via motor cortex and other regions outside the scope of the model) to motor pattern generators that convert that decision into the actual footsteps that get you to your goal. This part of the model concludes with registration of the consequences of the selected action.

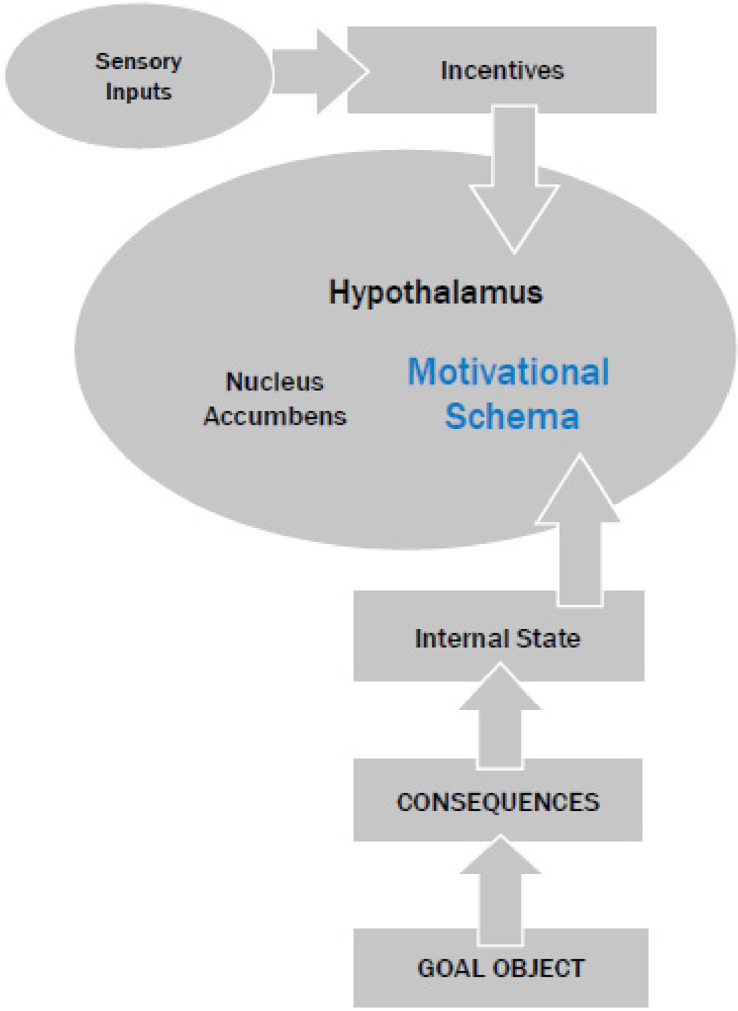


Figure 1.10: The Motivation System.

The consequences of the action provide the brain the data it needs to learn from experience, which may be positive (that action would be worth repeating in similar circumstances) or negative (let's not make that mistake again. The original work with Israel Lieblich, all of 40 odd years ago (Arbib & Lieblich, 1977), was based on behavioral data on motivated behavior in rats. A key point was that, of course, the rat's behavior (like ours) very much depends on its motivational state. If it's hungry, it'll look for a place where it can find food. If it's thirsty, it will look for a place where it can find water. If it finds itself near a place where it gets an electric shock, it will avoid it. Figure 1.10 thus focuses on the "motivational schema." The linkage of consequences to the internal state encodes such changes as "if you eat you are less hungry," "if you drink you are less thirsty," the incentives box reflects that, for example, the smell of food might increase one's drive to eat even if, in its absence, one might be only moderately hungry. The hypothalamus has the basic motor routines for handling hunger and thirst and fear and sex, and so on. The nucleus accumbens provides the basic learning mechanism.

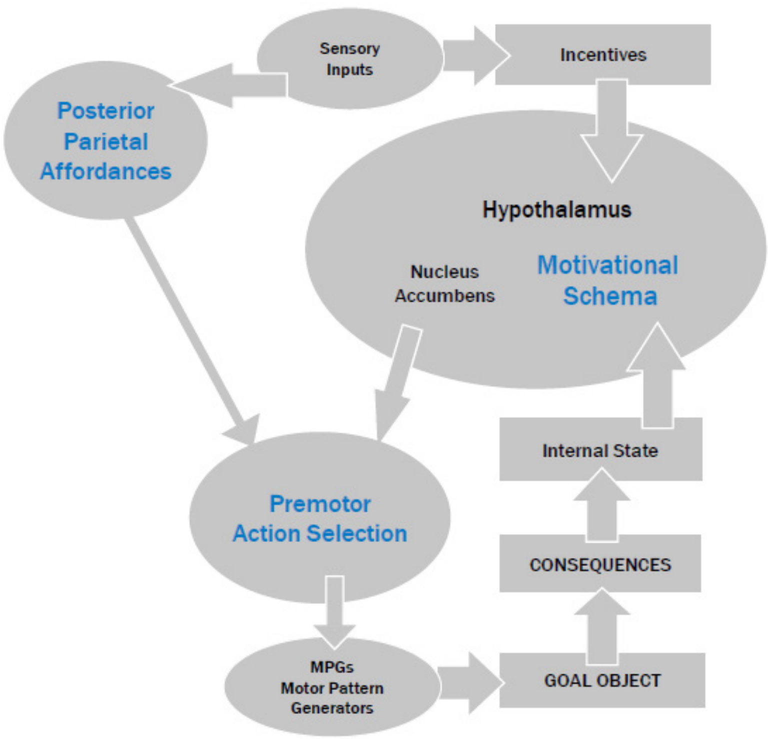


Figure 1.11: The complete Taxon-Affordances Model (TAM).

It can take the information about whether or not an action was successful in meeting a particular drive (hunger, thirst, fear, sex, etc.) and turning it into a bias for selecting one affordance over another depending upon the current motivational state.

Now that we have some clarity about the subsystems shown in Figures 1.9 and 1.10 we can put them together. Figure 1.11 begins to look a little complicated, but, hopefully, now that we have approached it gradually, it remains comprehensible and one can now see how the two subsystems work together. We have added one extra arrow – the one from nucleus accumbens to make explicit how the learning system can modify action selection in the rat or human whose ongoing behavior we wish to study.

With this we have completed the exposition of TAM, the Taxon Affordance Model. What might it mean for the architect to whom the details of neural networks or computational modeling may hold little interest?

Well, it suggests that in designing the building, one must take into account the varied motivations of users of the building, and not only provide affordances for actions which can meet their needs, but also take into account that a user may need to adapt to building to make comfortable use of it, and thus affordances which support learning can also play an important role. An example. I recently stayed at the Intercontinental Hotel in downtown Los Angeles. When I entered, there was no sign of a registration desk, but there was a sign pointing to "Lobby Elevator." Getting on the elevator, I could find no buttons to choose the lobby floor, and was discomfited to find that the elevator appeared to be headed to the 70th floor. The other passenger then explained to me that (a) one had to select one's destination on a touchpad outside the elevator, and (b) the lobby was indeed on the 70th floor. So I quickly learned how to use the elevators in the building and how to get to the lobby. The lobby, with its high ceilings, glass walls and dramatic view across Los Angeles was indeed an attractive, unusual, and memorable feature of the hotel – but the lack of visible affordances for getting to the lobby on first use was not. Note that the actual TAM model has no details within it to capture either my motivational states (find the lobby + frustration, discomfiture) nor features of the lobby that made arrival there rewarding. We have here the use of a brain model to anchor conversation about architecture, not neuroscience offering a detailed support for evidence-based design. However, an important side-effect of my example is that TAM lacks the ability to address a key aspect of my experience – that I was growing a cognitive map. By the time I reached the lobby it had 2 places (the ground floor of the hotel and the lobby) and the link between them (press 7-0 before entering the elevator on the ground floor). It was this phenomenon that Lieblich and I addressed in our introduction of the notion of the World Graph, WG (Arbib & Lieblich, 1977; Lieblich & Arbib, 1982).We initially introduced WG as a framework for analyzing how rats running mazes can exhibit detour behavior (Tolman, 1948), with their paths depending on their current motivation, but we posit that it is a crucial feature of human cognition, too. Generalizing our "two places and the way to get from one to the other," a World Graph is given by a set of nodes plus a set of edges that connect them:

- A node corresponds to a recognizable place in the animal's world.
- Each edge represents a path from a recognizable "place/situation" to the next.

A useful example here is the map of the London Underground (figure 1.5), where each node corresponds to a station, while each line between 2 adjacent stations actually corresponds to two edges of the graph, one for travel between the stations in each direction.

A recognizable "place" is one with distinctive features that may make it memorable. But a single place in the world may be represented by more than one node in the graph if, e.g., the animal comes upon a place in the maze for the second time but does not recognize that he has been there before, perhaps because it encounters the place in a different situation or motivational state. Each node not only encodes recognition features but also stores information about the utility of the place (this is for reduction of drives like hunger, thirst, fear in the rat model)

There is an edge from node x to node x' in the graph for each direct path the animal has traversed from the situation it recognizes as x to the situation it recognizes as x' without passing through another recognizable situation. Sensorimotor features appended to each edge, corresponding to the associated path.

Again, let's turn from rat data to the World Graph that you, the reader, have in your head. There are certain distinctive places in your world, certain recognizable places, and for each of those you have a way of getting to some "neighboring places." The little world map of

Figure 1.12: Two nodes represent places in the world; each edge represents a direct link from one place to another (in this case, a non-stop flight from San Francisco to Sydney).

Figure 12 represents a fragment of my World Graph, showing how I get from Los Angeles to Sydney. When I say "neighboring places," I emphasize that "neighboring" does not mean "nearby." I get on a plane in Los Angeles. I get off a plane in Sydney – that's just one edge of my WG. Other parts of the graph are on a smaller scale. How do I get to the airport from my home? Once I'm on the plane, I just sit there and eat and drink and sleep and tap away on the computer and watch the flight map or get bored (maybe I develop a small WG for the interior of the plane, to be discarded after my flight). At the other end, how do I get to my relatives' houses? You can think of this in architectural terms. Consider the affordances (TAM) that combine with their cognitive map (WG) to allow people to navigate within buildings or between buildings.

The full WG model shows how current drives, position as encoded in WG, and both appetitive drives (thirst and hunger) and avoidance drives (fear) change over time. Crucially, given our definition of a cognitive map, the full model shows how, if node x represents the current location and node x' represents a desired location, WG can find a path from x to x' which can then be translated into overt behavior as each edge on the path is read out as the corresponding action. But the details (Arbib & Bonaiuto, 2012) are outside the scope of this paper. Here I just want to note how WG may change over time, as mine did at the Intercontinental Hotel.

Figure 1.13 (bottom) shows how edges with unknown termini (i.e., unexplored affordances) can compete with other edges from a node x. If movement occurs along an unexplored and leads to a new place that is memorable, a new node x' and a new edge from x to x' will be added to the world graph, and each will be tagged with the appropriate defining features.

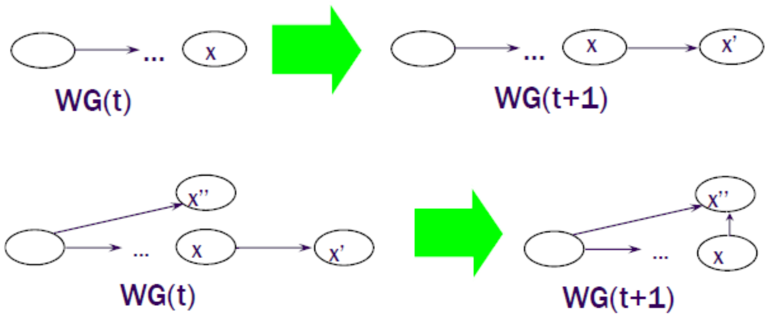


Figure 1.13: Exploration may add new nodes to a WG or collapse two nodes into one.

Figure 1.13 (top) illustrate the merging of previously distinct nodes in WG. If the animal thinks it is at P(x'), the place represented by node x' of WG, but then recognizes that the place is also represented by a different node x" then x' will be merged with x". Just consider exploring an art gallery and finding oneself unexpectedly back in a room one had been in earlier. At first it looks different because one has entered it from a new direction, or noticed paintings one had not noticed before. One has just added x' for a new room, then it "collapses" into the x" for the old room.

A very nice example of this goes back to the original O'Keefe style of experimentation. You place a rat in a radial maze, and you measure a variety of place cells to find the place field of each cell. In particular, you become able to identify from the firing of the cells which of the arms of the maze the rat is on. But now you add a little wrinkle. You put food at the end of each arm at the beginning of each trial. The rat develops the optimal strategy -- scurry up one arm, and eat, return to the center of the maze, then scurry up a different arm. It won't go to the same place twice because it knows the food is not replaced during a trial. In later trials, you put the rat in the dark.

Instead of using visual cues, it uses its own motion to update the firing of place cells that represent where it is in the maze. Every now and again, the rat will make an error and go up an arm it has visited before, and when this happens you find that the place cells are coding an arm where food remains, not where the rat really is. This exemplifies the issue of sensorimotor integration: How do your visual and tactile experiences register with your motor experience in locating yourself in an environment? Under what circumstances do the various cues get out of registration?

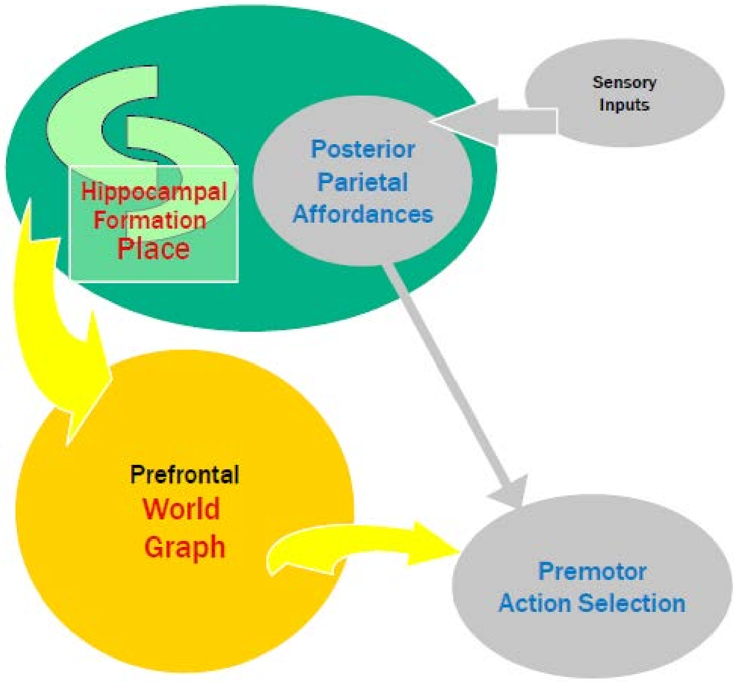


Figure 1.14 Introducing the hippocampus and the World Graph (WG) for the model

With this, we can comprehend the high-level view offered by Figure 1.14. The hippocampus registers where the animal is and updates the relevant node in the World Graph; WG (on the basis of some criteria about the goal) determines possible paths to a goal and then biases action selection to choose an action that lies on one of the paths and currently has available affordances. As each new significant place is reached the operation is repeated until the goal is reached.

With this, we can assemble all the different brain modules into Figure 1.15, which is at last (if I have succeeded in my exposition) comprehensible. In the integrated model, affordances matter even if we are navigating on the basis of a (cognitive) map, but the model can also support exploration until affordances for achieving the current goal are found. Indeed, recalling Figure 1.11 and the lobby of the Intercontinental Hotel, a cognitive map may be being built even in the latter (affordances only) mode. Whether or not that cognitive map

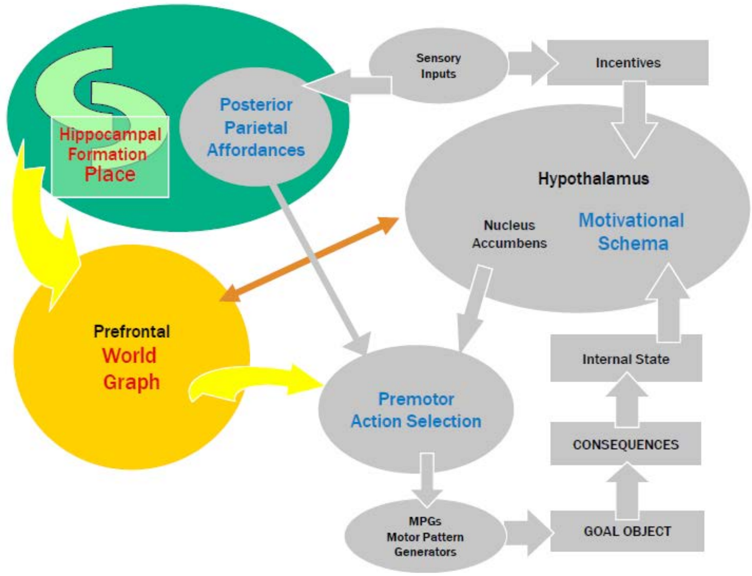


Figure 1.15: The complete TAM-WG (Taxon Affordance Model + World Graph) model.

becomes established in long-term memory will depend on contingent factors. Although it is not part of the TAM-WG model, we see ways to extend the model to allow part of the memory in WG to be externalized to the use of a paper map, whereas route following under instruction by a smart phone directions app short circuits the WG computations entirely, and we are basically reduced to relying on TAM, looking for the next affordance specified by the phone and acting as it directs.

Conclusion

I hope to have got across the message that it takes more than a hippocampus to build a cognitive map, while suggesting that, in terms of architectural design, there is an interesting combination between exploiting the underlying "script" for buildings of the given typology – what it is that you can expect people to know when they approach the building for the first time – and providing an element of surprise. The visitor to Lina Bo Bardi's Sao Paulo museum finds famous paintings in elaborate frames. Expectations about being able to admire great art are met, but the visitor's "default" cognitive map proves useless. A joint challenge for architects and neuroscientists, then, is to go beyond the add-a-node-and-an-edge style of building a cognitive map of Figure 1.12 to get a better handle on the "scripts" that allow people to generate cognitive maps when they experience a building of a given typology for the first time. Such a "map" goes beyond wayfinding to incorporate the variety of actions the building affords (which may include interaction with other people, adding a dynamic component to the environment that even a static building provides). The challenge for the architect is to provide an environment which enables people to map the environment to meet their needs, while offering a measure of aesthetic satisfaction and adding that frisson when expectations are departed from without causing undue frustration in doing so. It takes more than a hippocampus not only to build a cognitive map, but to defy the visitor's initial expectations for a building's cognitive map in an architecturally pleasing way.

Dr. Colin Ellard & Robert Condia

Place, Peripheral Vision, and Space Perception: a pilot study in Virtual Reality.

Figure 2.0: Museum of Costelvecchio/Carlo Scarpa, 1959-73/Photo by Bob Condia (2015)
Good architecture, which defines a place, is always a composition of visual fields, focused to peripheral.

In our presentation, we are going to discuss the role of peripheral vision in space perception, including an experiment that we conducted in Virtual Reality. We will begin by giving an overview of the science of vision relevant for architects —or Vision 101 for architects. We will explain that there is a bias in the common view of how the visual world is taken in, and we will dispel that bias. Of special importance will be the difference between perceptual experience as it is given through the central visual field and through the peripheral visual field (Figure 2.0). Following this, we will describe our experiment.

In the realm of pop science, we are still sometimes exposed to the myth that we use only 10% of our brain. This, of course, is not true. We use 100% of our brain, but we are not conscious of all of our own brain activity. Much of brain function is devoted to sorting through the flood of sensory load and constantly formulating (and reimaging) some approximation that we refer to as reality. Just as important to understand is that we are not simply brains in vats. By that we mean that understanding neuroscience and behavior means recognizing that the distinction between brain and body is artificial. Indeed, even the distinction between our own body and the rest of the world is somewhat artificial. We are a mobile nervous system. In a way, architects have always known this, considering their truthful intuitions for the manner in which the entire body is involved in the sensation and calibration of space. Neuroscientists, though they have fleshed out this story, have come somewhat late to the game!

Here is a really simple neuroanatomy primer that you can demonstrate to yourself using your own body. Hold up one hand and bend the knuckles of your index and middle finger. Think of this as the brainstem. This part of the brain controls what are sometimes called vegetative functions: breathing, heart rate, and homeostasis. Now wrap your other hand around those knuckles to represent the hippocampus and the basal ganglia. Finally, put both hands together to see a facsimile of the cerebral cortex, which has evolved for planning, language, and higher-order thinking. The thing you hold before you, modelling the engine of thought and feeling that resides between your ears, consumes about twenty-five percent of your body's energy resources. Of course, these words represent a gross oversimplification of the structure of brain tissue, but we're trying to boil things down to their utter essence (Figure 2.1). What must be known, at a minimum, about brain structure and function in order for architects to make sense of the potential for interplay between neuroscience and architecture? Explicitly that the brain and body are a singular organism Figrue 2.2 which sees beyond mere vision.

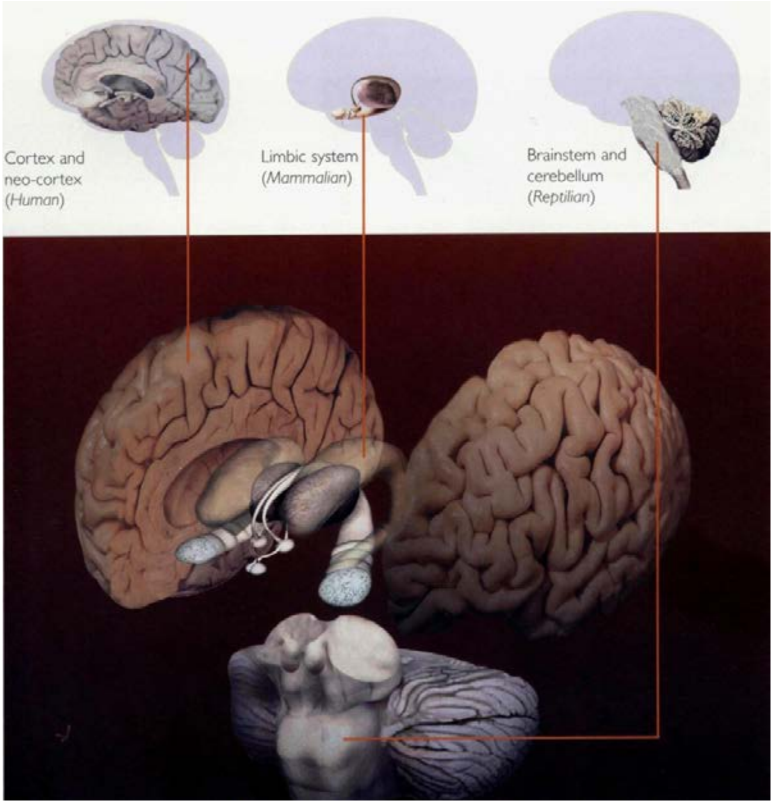


Figure 2.1: Different parts of human brain. ttps://bladymamut.wordpress.com/2013/08/

Figure 2.2: Image ilustrates how you are a mobile nervous system.
http://www.hormonesmatter.com/fluoroquinolone-antibiotics-associated-with-nervous-system-damage/

Common experience of architecture begins (and for some ends) with the optics of vision. Turning then specifically to the visual system, let us begin by making one of the most important distinctions known to visual neuroscientists: the contrast between center and periphery. Continuing with our theme of demonstrations of the basic facts of neuroscience using the body, hold your thumb out at arm's length and look at it. By those words "look at it," what we really mean is that we are asking you to direct a particularly small part of the neural machinery for vision at your thumb. Your fovea, a small patch of tissue in your retina, only subtends about 5 degrees of visual angle. Translated into the stuff of the world, that thumb that you're staring at is about a fovea's width wide when held at arm's length. What is significant about this is that this part of the visual system is the beginning of all high-resolution, detailed vision and all color vision. To get a sense of what that means, look at Figure 2.3 which shows an artist's conception of the manner in which visual experience varies over the geographic extent of the retina. As you can see, detail and color only come to us through one small part of the retina. The rest of the visual world, the periphery, is more or less grey-scale and shows only blobby, low-resolution image. That there is a difference between central and the periphery of your visual information likely comes as a declaration to you?

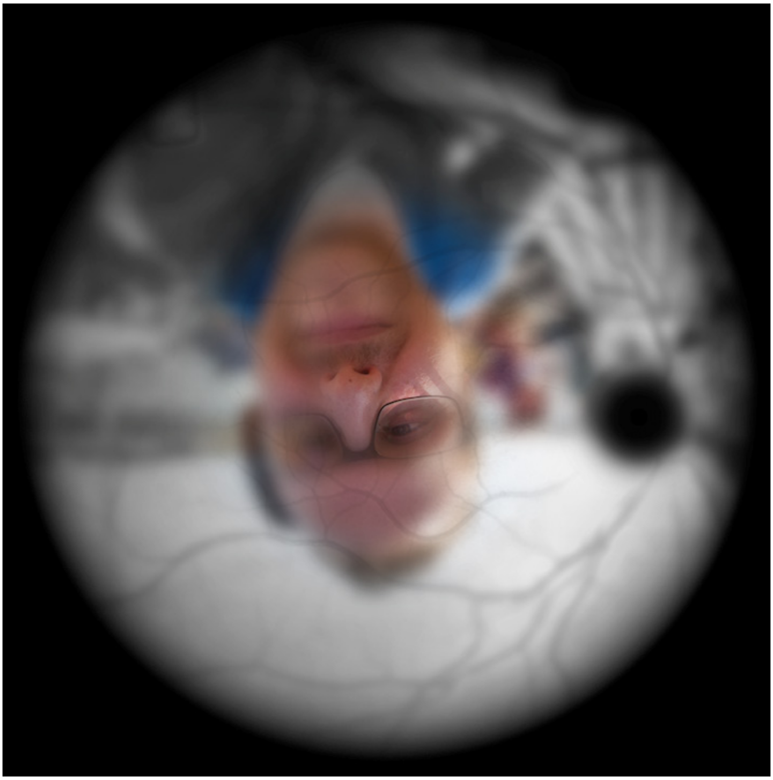


Figure 2.3: Artist's rendition of how the world appears to the early part of the vision system.

What is most remarkable about this is that what you see in Figure 2.3 certainly doesn't feel like your own phenomenological experience of vision. We experience the world as if it exists in full-detail, colored panoramas. Neuroscience shows us that this experience is misleading, a kind of carefully orchestrated dance that is put together through artful arrangement of a series of brief glimpses (fixations) separated by quick movements of the eyes (saccades), all reassembled behind the scenes into a seamless, stable percept of the larger world. This is a great example of the kind of work that is being conducted by that 90% of the brain whose work is largely inaccessible to consciousness.

Beyond the retina, the human visual system occupies an enormous part of the entirety of the central nervous system (in primates like us, more than half of the brain can be considered to be "visual" in one way or another). In the cerebral cortex, there is a strong tendency for modular organization—we have dedicated processing systems for form, motion, colour, depth and, beyond these low-level parcellations of visual function, we have areas dedicated to processing more complicated aspects of form vision and spatial vision. Through all of this complexity, though, the distinction between the center and the periphery that begins in the retina persists through the rest of the system. Though it's not a perfect fit, there is at least a rough correspondence between the central and peripheral visual system and the division of labor shown in Figure 2.4, in which we describe the dorsal/parietal system as being more closely associated with the peripheral visual field and the ventral/temporal system as being connected with the central visual field.

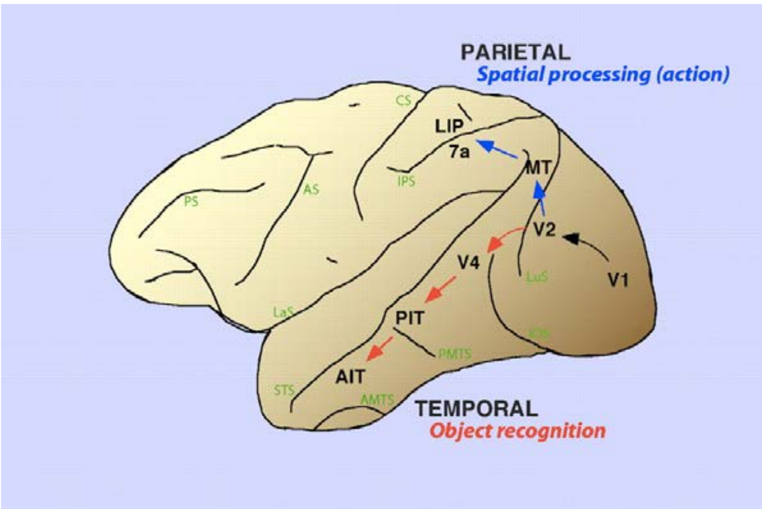


Figure 2.4: Illustration of the different parts of the brain.

In general terms, we say that the dorsal visual stream is specialized for processing information about space, especially where that information must be used for motoric interactions with the world. Movements of the eyes, reaching and grasping movements, and, to some extent, the manner in which we deploy attention to the world are the special domain of the dorsal stream. In contrast, the ventral stream is thought to be involved in processing the details of form required for the identification and recognition of objects. This being said, it's worth emphasizing that although an enormous amount of information from a wide variety of different types of studies supports this basic distinction (Goodale and Milner for review), it should be considered as a first approximation, especially bearing in mind that most ongoing visual behavior involves close interplay between the two separate processing streams that we have identified.

The division of labor between the two main visual processing streams is just one example of a fact of vision that has been understood intuitively by architects for a very long time. Vision involves more senses than simple optics. It encompasses a broad range of different types of capacities, with an especially important role for the body. When we visit or use a building, we typically don't take it in from stationary viewpoints as we might do if we were looking at a painting or a photograph. Instead, we, as observers, are in constant motion, painting the scene into our nervous systems by means of a calibrated dance of eye, head, body and limbs. In such a dance, the distinction between center and periphery is paramount. One can obtain a very good sense of the separate contributions of center and periphery by considering a technical procedure that is in common use in perception labs (for example, the laboratory of Lester Loschky at Kansas State University), where movements of the eyes are tracked and the scene that is presented to the eyes is carefully manipulated in synchrony with eye movements. So, for example, it is easily possible to introduce a visual mask so that the viewer is only able to obtain visual information from central vision (the central 5 degrees for example) or from peripheral vision (the rest of the visual world outside of the center). Figures 2.5 a and b, show schematic views of what the observer would be able to see under such conditions. Even without participating in the experiment, it isn't hard to imagine its effect. Confining vision to the central field makes it straightforward to identify objects (say, a coffee cup) but much more difficult to get a sense of space and location. Occluding central vision but leaving the peripheral field intact, on the other hand, makes identification of details of objects much more difficult. For example, it becomes impossible to read.

So although it is probably not wise to make too much of the distinction between center and periphery—one must work hand in glove with the other for there to be normal perceptual function, for example, even reading is affected by occlusion of the periphery. Words can still be identified but fluid processing of text, which involves anticipating

Figure 2.5a Example illustrating peripheral vision courtesy of Kevin Rooney.

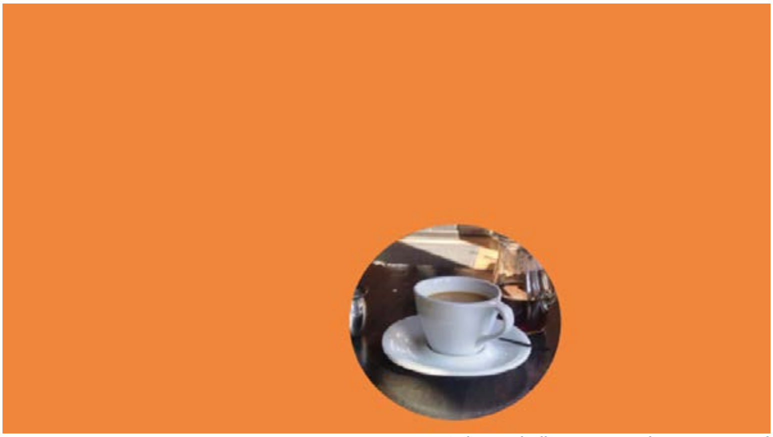


Figure 2.5b Example illustrating central vision courtesy of Kevin Rooney

future text by attending to the periphery, is hindered (Rayner and O'somebody), the two parts of the visual field do seem to make different kinds of contributions to the visual experience of architecture. Although our conceit is the world is what we see, our dance in the world is more than mere optics.

Furthermore, it is possible to switch attention between the center and the periphery. Figure 2.6, taken from a recent paper by Kevin Rooney and collaborators, illustrates the interplay of center and periphery during architectural experience. The center, with its strong contribution to objects and details, tells us what things are. The "whatness" of a scene is a necessary foundation for conscious experiences of empathy from which the aesthetic of a building emerges. Peripheral vision contributes to what architects describe as atmosphere or mood—properties of an interior lent to it by its spatial properties.

To say space or architecture is aesthetic acknowledges ones empathetic and sensory experiences of the felt-world. The complex messiness of real space. Our distinction of aesthetic here isn't the subjective eye-of-the-beholder (which by the way isn't consistent with today's science), but the pre-reflective, emotive and non-verbal communication assimilated through the body. Very much like dodging

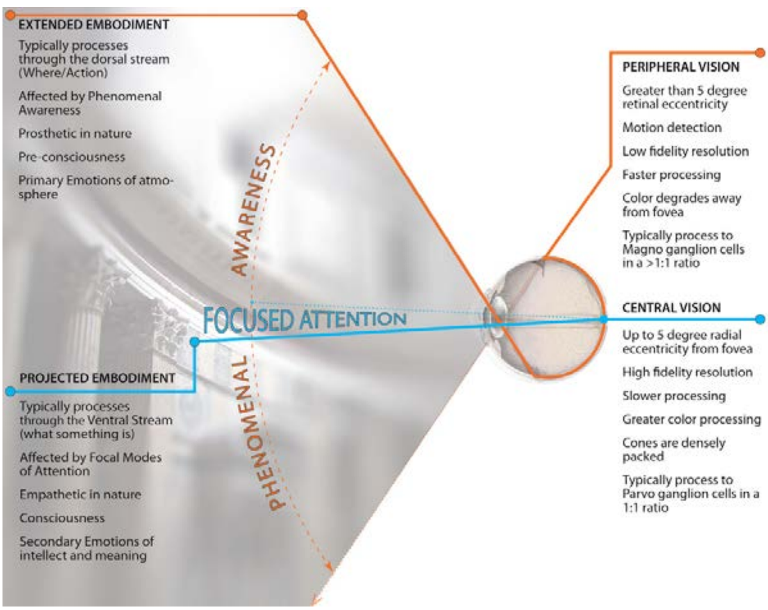


Figure 2.6: Diagram showing split between central and peripheral vision courtesy of Kevin Rooney

a charging tiger well before you know you are scared. Emotion means motion or action. And although under played in a Cartesian philosophy the contribution of emotions in cognition is significant. Hence, there is some wisdom in thinking about this in terms of basic emotions. Figure 2.7 sketches (albeit simplistically) an axis between fight-or-flight responses and pleasure or hedonic circuits. Although the level of one's emotive connection to space is arguable, for architects the lesson is the scope for cooperation between the central and peripheral visual systems. We catch a glimpse of movement in the periphery. It's enough to prompt us to focus our central vision on the target and recognize a tiger. Let's get out of here: run. In a building flight response might be elicited by under scaled structural members, harsh lighting, shiny un-natural materials, or open office desk farms. On the other hand, there are pleasure responses, which might also be driven by the same kinds of connections. We detect a pretty face and we are rewarded for examining it. In an architectural setting this will be the romantic mood set by lighting and music, the composition of a sculpture into a niche, or finely crafted details set within the central frame of vision.

The contributions of the visual periphery can certainly go beyond simple flight responses or pleasure impulses though. They can

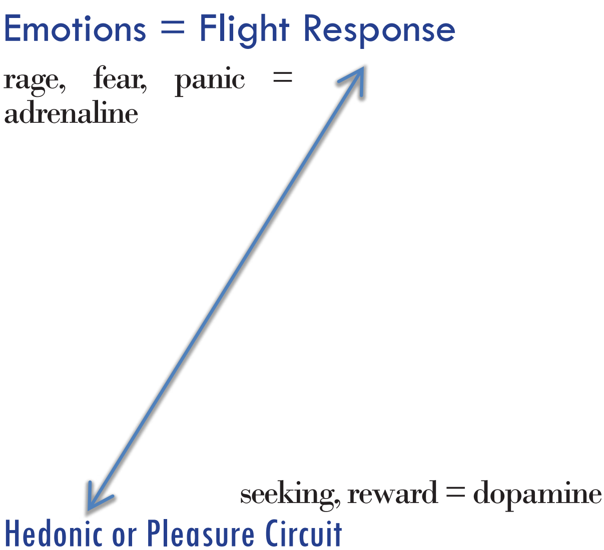


Figure 2.7: Emotions Diagram

be much subtler. In the image below, Figure 2.8, we see a photograph of an awe-inspiring environment. One key element of settings that generate awe is that they have immensity, and the most immediate way of detecting immensity must involve the peripheral visual field. So, immensity contributes to the feeling of awe, which in turn can produce a cascade of effects. When we feel awe, we may feel smallness of self, but we also become kinder, more prosocial and more philanthropic. So, in a sense these kinds of behaviors can also be produced by the visual periphery.

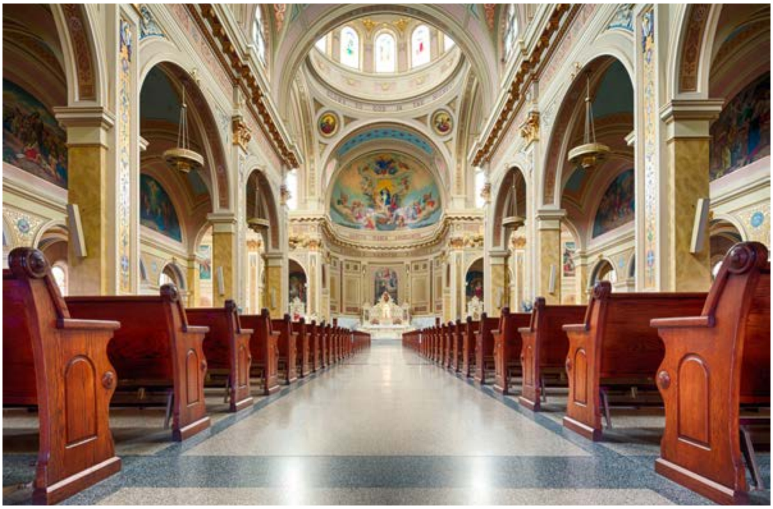


Figure 2.8: Awe-inspiring environment.

Another contribution of the peripheral visual field comes from its involvement in what geographer Jay Appleton called the duality of prospect and refuge. Building on basic principles of animal behaviour and habitat selection, which show a general preference for locations from which animals can see but not be seen, Appleton suggested that human beings possess ancient circuits which similarly draw them to locations from which they perceive themselves to be sheltered in refuge, yet also possess a view into the world, showing both possible threats but also possible bounty. The image, Figure 2.9, shows a location in the aptly named Prospect Park in Brooklyn, where the arch provides a sheltered location from which to view high prospect.

Our collaboration between neuroscientist and architect, which is to say our goals - are well framed by Dr. Michael Arbib's proclamation, "It is in the very nature of science that it succeeds by focusing on parts of the whole. The challenge is to determine which the "right" parts are, and how lessons gained from the study of separated parts may provide a firm basis for study of the larger system formed when the parts are combined." M.A. Arbib (2013) So for architects to speak to scientists and to learn something of their game so that we find common language. How can we inform scientists and say these are the kinds of things that we need to study to improve our architectural spaces?

We have a mutual interest in how vision of the periphery effects spatial experience. In order to exercise this intersection between architecture and science, we designed an experiment in which we could try to separate the contributions of central and peripheral vision to an emotional experience in an architectural setting, and it turns out that to nobody's surprise, that's not a very easy thing to do. The approach that we decided to use for now was to design virtual environments because of the relative ease with which we could control what participants were seeing. The figure shows extremely happy people working in the Ellard Lab, but more importantly gives a glimpse of the methodology used in the experiments we will describe where we immerse participants in a 3D model of a built structure and then measure their response to the setting.

Figure 2.9: The arch of refuge at Prospect Park, Brooklyn.
Duality of prospect and refuge.

Figure 2.10: Place, Peripheral Vision, and Space Perception: a pilot study in Virtual Reality, Ellard Lab. University of Waterloo (Courtesy of Colin Ellard)

The first problem, how do we design virtual environments to study basic architectural spatial experience? For our pilot study, we needed strong contrast to insure results, so we decided to make something "good" and something "bad" by architectural standards and then to compare human responses to the two spaces. To make something good we used a rather complex set of aesthetic decisions and protocols and criteria based on a broad spectrum, based on ideas shown in the figure 2.11. We began with a broad section of criteria from philosophy and architectural history, using the overlaps, condensed down into beauty, order, ambiguity, economy, balance and composition. This array suggested designing a classic urban square and a modern square in Roman like proportions. Some of Colin's earlier work had shown that people respond negatively to smooth, unbroken glass surfaces, so based mostly on that and our aesthetic criteria, we agreed to express classicism as "good" and modern "flashcube" designs as "bad" for the purposes of this study.

VITRUVIUS	SCRUTON	KAPLAN	GESALT
Order	Imagination	Coherence	Occupation
Arrangement	Empathy	Legibility	Grouping
Eurythmy	Ambiguity	Complexity	Similarity
Symmetry	Apropriate Detail	Mystery	Proximity
Propriety			Parallelism
Economy			Symmetry
			Figure-Ground
			Part-Whole

BEAUTY | empathy . dynamysm . eurythmy . metaphor

ORDER | concinittas . wholeness . coherence . whole to part

AMBIGUITY | mystery . interpretive value . imagination

ECONOMY | appropriateness . suitability . refinement

BALANCE | symmetry . contrast . mass + void

COMPOSITION | arrangement . alignment . proximity . repetition

Figure 2.11: The aesthetic experience array, developed in architect's lab as an aid to construct good amd bad spaces.

A second set of constraints were that people have a limited tolerance for virtual reality (VR) environments (wearing the headset), hence the design of an experience that lasts roughly three minutes. Assuming a gentle pedestrian pace of two miles per hour, this helped us to scale the model. We designed two urban squares (classical and modern), each a double square of fifty by one hundred feet, planning for the participants to walk a loop through each square Figure 2.12. The historic square was in the classical style, figure 2.13a. We limited the parapet height to fifty feet, the typical height of a four-story (and attic) pre-elevator building in a historic city like Paris, London, or Chicago, figure 2.14. Our facade treatments were rather literal, as classicism can be: we appropriated the Parthenon at the short end and mirrored Michelangelo's facades from Rome and a Beaux-Arts heavyweight structure to carry the opposite axis and the arched space for the participant questionnaires. The modern (or flashbulb) square was identical to the historic one in proportion, with many glass surfaces and relatively low levels of facade complexity, figure 2.13b. It echoed the proportions of the classical square because scientific comparison required that the number of measurable differences between models be kept to a minimum. In both models, we located a twelve-foot-tall reflective egg at the distance of the golden section. This referenced the historicity of points of interest—such as fountains, sculptures, and temples—in urban plazas and provided emotive interest for our inquiry about central versus peripheral vision. Between the two, we put a Renaissance Beaux-Arts building, which housed an interface where participants could be asked questions of the gaming interface and give answers while in this small vaulted space (Figure 2.15).

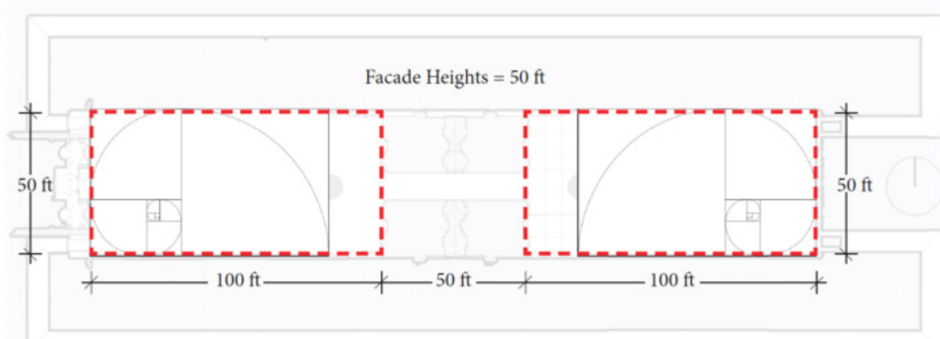


Figure 2.12: Plan

Figure 2.13a: Classical square

Figure 2.13b: Modern square

Figure 2.14: Building Section

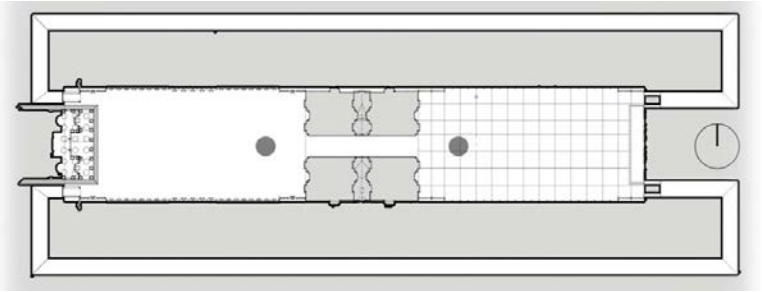


Figure 2.15: Floor Plan

Aesthetic experience (in architecture) is a combination of thinking and feeling. For the human response measures, we used a combination of physiological and behavioural measures. Our physiological measure was electrodermal activity (EDA), which will be discussed by Brent Chamberlain in his essay. To reiterate the main points, EDA is a coarse measure of activity in the autonomic nervous system, which provides us with a measure of arousal based on sweat gland activity. It is always worth remembering with EDA that the measure is agnostic with respect to the valence of emotional state. As everyone knows, we can be aroused in either good or bad ways, and the EDA measure alone can't tell us which is happening. In our experiment, we solved this by combining measures of EDA with measures of self-assessment questions, where we asked participants to indicate their emotional state by way of a gaming interface in the connecting arch between the two squares, immediately following their experience of the space.

Experimentally, the next challenge for us was that we wanted to find a way to separate out the central and peripheral contributions to the development of emotional state in the models. To do this, we used a mask (as shown in the figure 2.16), which either blanked out the central 10 degrees of the visual field (the peripheral condition) or it blanked out everything except for the central 10 degrees (the central condition). We also had a control condition, which had no mask. Of course, though, in normal experiences of settings, we are moving bodies, heads and eyes and for this experiment we had no simple way to ensure that participants had restricted vision while in motion. To solve this, we had to compromise. We designed a carefully constructed simulated walk-through, where participants were asked to fixate a cross while they were transported through the two squares, one by one. During the walk-through, they experienced the environments as a series of brief flashes, each one short enough so as to prevent eye movements during the "walk." In this way, we could be reasonably assured that the images of the environments were being restricted to either the central or peripheral visual fields.

Figure 2.16: The three viewing conditions.

The image below, figure 2.17, summarized the EDA results from our experiment. There are eight clusters of bars from left to right. Each of those clusters of bars represents a single ten-second epoch in exposure to the models. Each plot begins at the left with the moment of exposure to a model and then continues on until the eighty-second mark where the walk through the model ends. The bars within each of those epochs separate out both the three conditions (central, control, and peripheral), and the two models (modern and classical).

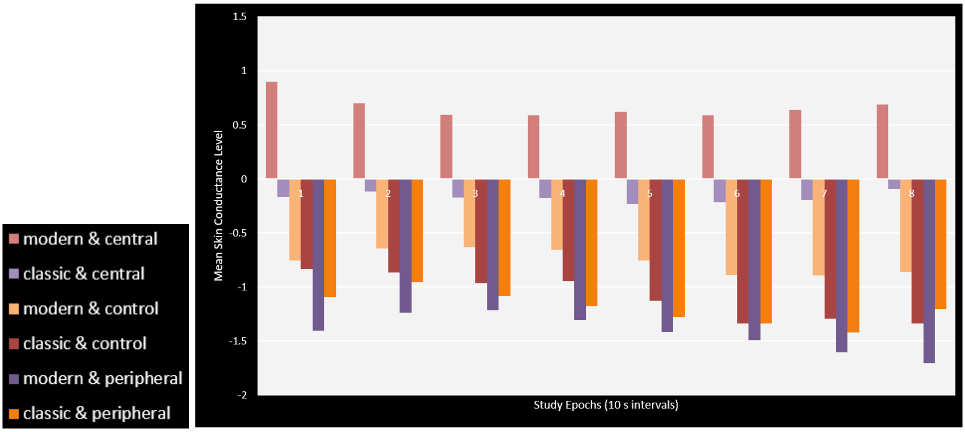


Figure 2.17: The psychophysiological results of the main experiment. Each bar represents the average value for skin conductance over a ten-second epoch beginning with the presentation of the model. The eight sets of bars arrayed on the horizontal axis show the eight different epochs of the experiment. There are separate bars for the two models (classical and modern) and for the three viewing conditions (central, control, and peripheral), as indicated in the accompanying legend.

The plots look very complex, but there's one very notable feature. The conditions that produce the highest levels of arousal are those of the central condition, in which the participants could see only the central ten degrees of the visual field. As we said earlier, though, an EDA finding alone will not tell us how our participants feel, only that they are aroused. To dig deeper, we turn to the answers to subjective questions. The figure 2.18 to the right shows a compilation of responses to a question about what is called "restorative potential." This scale is meant to measure the extent to which a participant feels that a particular setting might make them feel refreshed, removed from an everyday environment and relaxed. The construct of restorative potential is often used, for example, in studies of the impact of natural

Figure 2.18: Han's emotion subscale, plotted separately for the models.

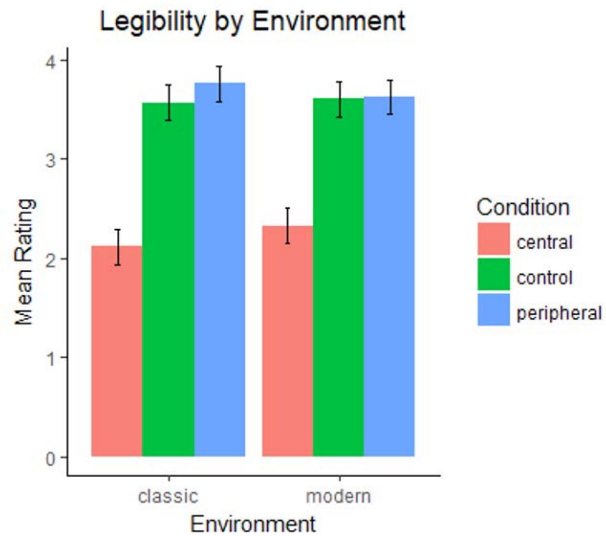


Figure 2.19: Self-assessed legibility scores for the three viewing conditions. Participants found the central condition significantly less legible than the other conditions. There were no differences between the legibility of the control and peripheral conditions.

environments on human emotional and cognitive state. As you can see from the graph there is a difference in perceived restorative potential between the central condition and the other conditions. Not only this, but the classical environment shows significantly higher levels of restorative potential than does the modern environment. This is a subtle finding, which provides a tantalizing clue that differentiates the response to central and peripheral visual fields being filled with one or the other architectural style. It's not enough to build an edifice of theory on, but it's a beginning!

The next figure 2.19 shows comparisons of participants' evaluations of the legibility of environments. In a way, even asking this question seemed superfluous to us because participants came out of the central condition with complaints about their inability to understand what was going on and where they were. This shows clearly in the graphs, where the central condition was rated as being significantly less legible than either the control or the peripheral condition and, interestingly, the control and peripheral conditions did not differ. In other words, there was no evidence that removing the central 10 degrees of the visual field had any impact at all on legibility. But removing the periphery resulted in a taxing, unpleasant, physiologically arousing experience.

Where do we go from here? For one thing, we move from the use of artificially rendered virtual environments to settings that are more realistic by using video collected in the field (perhaps even 3D immersive video). But a step beyond that would be to go into the real world itself, taking advantage of new generations of technology that allow eye-tracking and perhaps augmented reality devices in the real world, making possible the kinds of mediated exposures to central or peripheral views of real world settings.

Acknowledgments

The authors are grateful to The Richard H. Driehaus Foundation—and especially Kim Coventry, executive director—for supporting this pilot study and organizing and hosting the symposium Architecture as Experience: Human Perception of the Built Environment, held September 30, 2017, in Chicago, which brought the authors together. We are also grateful to Dr. Harry Mallgrave, who served as a consultant to the Driehaus Foundation for the symposium. We must acknowledge our graduate researchers for their work constructing and conducting the study, particularly Jastheeth Srikantharajah, for exceeding the call of duty to run more than seventy participants in only a week and conduct the preliminary experiment; Richard Marion, for programming our gaming environment; and Andrew Huss and Alex Blair, for constructing the models of the two environments.

All figures and illustrations are by the authors except as noted.

Figure 2.20: Go-Pro with eye-tracking experiment.

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Rocks from the Neolithic Age, Callanish, Island of Lewis Scottland, c. 3000 B.C. - Architecture and central-peripheral vision combine monumentally.

Dr. Brent Chamberlain

The Physio-Affective Built Environment

Figure 3.0 How can we measure ourselves in space in this time of so many devices?
"Emma among the faces" at the main stair Villa Farnese/Image by Bob Condia (2015)

Introduction

Thank you, Dr. Rooney. Thank everyone for coming. I told Bob before I came here I felt a bit like the unknown local garage band that was opening for rock stars. So, thank you very much for the invitation.

What I'm going to be presenting today is some work that has been in progress for a few years, with significant headway being made these past few months by two graduate students: a PhD student, Heath Yates, and a Master Regional and Community Planning student, Taylor Whitaker, they just defended their PhD dissertation and their masters report, respectively. What I am presenting today is very new in terms of its results, I think and I hope that you'll be able to find some association with the way that we look at space, structure, and our affective response as we experience these. Much of this work I am presenting today comes directly from these students efforts and I have them to thank for their tremendous contributions.

Many years ago, I heard a talk by Daniel Quercia on something called *Happy Maps*. The concept focuses on what garners our emotional experience towards happiness? This sort of inspired me to think, "What kind of environmental characteristics influence happiness as we look about urban areas?" What influences the way our perception and feeling at the physiological level, things that may affect our heart rate, things that affect our stress, things that affect fear, things that affect emotion broadly.

Imagine for a moment, a busy intersection in an urban area (Figure 3.1). You are standing at the edge of a crosswalk looking across the road, surrounded by a number of other pedestrians. All around you are cars, buses, overhead electrical wires, skyscrapers, signage, traffic lights, towering trees and restaurants and other common urban infrastructure. While you may not be concerned with the overhead infrastructure, the person next to you may feel a bit uncomfortable because they are visiting the city and not used to the sheer volume of overhead power lines. Somebody close by is getting bumped because it's a very crowded space and wasn't necessarily designed for the intended of open individual walking. Somebody may be more relaxed at a crosswalk. Somebody may be enjoying the trees around them. These are all facets

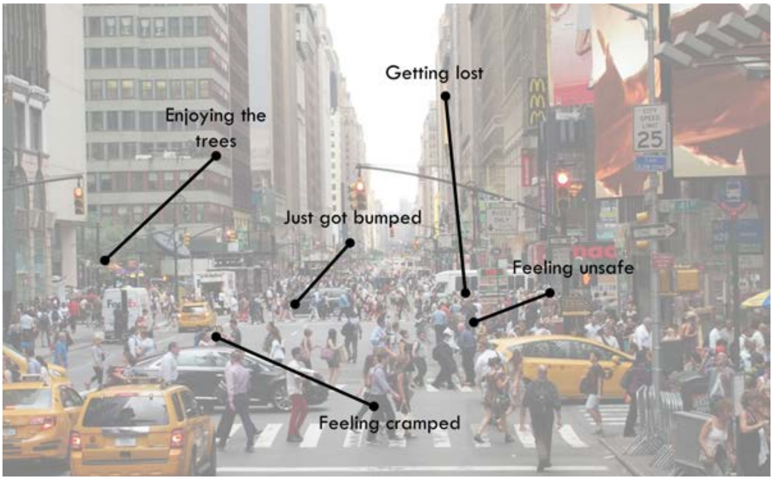


Figure 3.1: Some examples of the growing amount of information that exists in urban contexts.

of built environment that influence how we feel in space. There's been an extensive amount of literature and research has been done to look at particular environmental characteristics, and the way that they influence our affect.

We're interested in looking at this from a real-world context rather than a controlled laboratory experience. So the premise of this is that our natural environment, our built environment, influences us. We know that it has influences in terms of our mental health. Whether that's by performance on examinations from classrooms, to effecting cognition, down to the level of being able to remember or have a more extensive memory of recency and short term memory (including tasks associated with cognitive executive function).

With the surge in the Internet of Things and the linkage to urban health and well-being we have a potential to harvest a ton of data and use it to benefit how we do architecture, planning and design from urban context.

The idea of smart cities leverages methods that we can use to, start evaluating, in real time or over a long period of time, some of those environmental characteristics that do affect us. Not just emotionally, but also physically.

Premises and Questions

Premise: Our built and natural environments influence our mental health and well-being, effecting cognition, memory and emotional state. It offers unparalleled access to assess human–built-nature interaction

Questions: To what extent do different urban environmental characteristics affect arousal responses in users? Can we isolate characteristics using machine learning to identify meaningful human-built-nature relationships?

So we're looking particularly what infrastructure elements we believe affect us. And can we find a way or a method to collect this information over a long period of time in other contexts?

To do this we had to develop a structured assessment method that could be trialed locally (Manhattan, KS), but we're interested largely in the methodology whereby we'll be able to take a lot of other data, or mine other data, as it grows into the future and be able to extract an association between environmental characteristics that people see or experience in a particular location, and how that influences us in terms of affect.

Some of the researchers that have influenced my own work and many in my field are listed below. One of these most influential individuals is Roger Ulrich, a psychologist who really studied the way in which nature would influence stress and a recovery from stress. The Kaplan's were very significant in providing context, like prospect, refuge and mystery. The kinds of things that evoke emotions in a space.

Background

Recovery from stress can be expedited by exposure to nature (Ulrich 1981)

Living in highly urbanized environments may induce greater risk of stress and mental fatigue (Kaplan, 1989, 1995)

Viewing urban vs natural scenes influenced physiological response (Tsunetsugu et al 2013)

Knowledge could influence policy for urban design and development (Groenewegen, et. al, 2006)

In addition to real-world experiences, we started with an idea to look at images of urban scenes. Just at flat, two dimensional scenes to see if they could convey similar experiences as real-world feelings to determine or detect whether or not we would see physiological responses. In comparing between nature types of experiences and urban types of experiences we wanted to see if there would be statistically significant influence in heart rate. There are notions that these physiological responses do exist. Bill Sullivan and colleagues, University of Illinois and Taiwan University, have looked at fMRI imaging very recently to explore effects on the brain activity.

In terms of Landscape Architecture and Community Planning, when we look at policy development and landscape or urban design, We are interested in the kinds of things that we could assess and use from the study to encourage or develop policies that would be more appropriately related to how we as humans experience and are affected by the environment?

Sequential Ideas + Processing

- *Policies and theories of built-environment abound: form, function, space, technology…Empirical evidence?*
- *Passive, long-term measurable affect in real-world…too many variables?*
- *Affective computing offers methods for evaluating…intelligence to discern affect?*

So, broadly, looking at the policy aspect, what is it about those policies that we have? What is it about the theories that we develop? We create policies based on theory and precedent, and the question is: where is the empirical evidence?

There's a lot. But we're also looking for a real-world context, which unlike well-structured laboratory experiments, can generate huge amounts of data and variability. What about the sort of passive or long term effects? Instead of these traditional laboratory-based experiments, or these one off experiments, what if we had data collected over weeks, or months of time? Where we could delineate the differentiation between environmental characteristics, social characteristics and interactions in space? Then, to accomplish this, we can look at a field called Affective Computing, which began several decades ago and has reemerged in new ways recently to look at different machine learning methods to help us understand those different contexts and the associations with environmental variables, together with colleagues in computer science, we are exploring these methods as a viable option for assessing human affect in the built environment.

Collaborators

- *Parker Ruskamp*
  Landscape Arch.
  MLA Student - Experimental Design

- *Heath Yates*
  Computer Science
  Ph.D. Candidate - Machine Learning

- *Taylor Whitaker*
  Planning
  MRCP Student - Geospatial Analyses

- *Bill Hsu*
  Computer Science
  Professor Machine - Learning Lead

- *Brent Chamberlain*
  Landscape Arch.+ Planning
  Assistant Professor - Project Founder

Before we progress further, I wanted to acknowledge all the tremendous collaborators after the work by Heath Yates and Taylor Whitaker recently, I would prefer to be giving a presentation along with them, but the ball had started to roll before we had a substantial amount of their work completed. So, a sincere thanks to them. To give you some context of the timeline, back in 2015 (Figure 3.2), a landscape architecture student, Parker Ruskamp, really started this work where we developed a lot of the experimental design together. The images used in this presentation come from work that these three have completed in their theses and dissertations.

Heath Yates and his supervisor and my colleague, Dr. Bill Hsu, worked on the data Parker generated trying to derive some sort of machine learning methods from that, which we have published. Then Taylor Whitaker, a Regional Community Planning student, was able to take that work in this last year and really focus on identifying and characterizing different spatial characteristics within the environment through geospatial modeling.

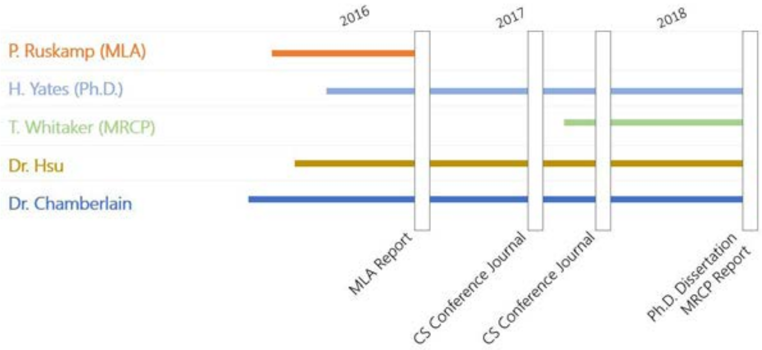


Figure 3.2 List of collaborators and a timeline of their respective projects.

Figure 3.3 Parker Ruskamp experiment lead subjects on a path through downtown Manhattan Kansas

For those who are interested, Parker Ruskamp has published his Masters report on a site called K-Rex through Kansas State University. We have a few conference journals, which I'll show at the end, that you can reference that are based on different iterations of this work. And then also the dissertation from Heath Yates is going to be coming out soon, and a Masters report from Taylor Whitaker.

I put these on here just for acknowledgment for people who want further details about this work. Secondly, I put it on here to let you know that as I'm presenting, we've had many iterations of this work. This has been a team effort and really strengthened how we invoke the scientific process, more and more questions. So this is a continuous process. What I'm going to be showing you are various snapshots of this work as we progressed.

This is downtown Manhattan, KS where we ended up having people go on a walk. I'll explain this in more detail later, but for now I wanted to give you context of this space.

Downtown Manhattan, Kansas. We had people start their walk from the Hilton Hotel where they were introduced to his study, we collected baseline data, then we sent them out on a walk (Figure 3.3). Here they're walking along 3rd Avenue North where has been a lot of new development. Sidewalks are largely concrete with brick clay pavers. Wider streets. It's well lit. There's a large mall along this road. After several minutes, they move westward on Poyntz Avenue, which is a commercial district with a large number of different facades, small buildings, small businesses.

Then we had them turn north and then they proceeded down a back alley, behind the two large buildings in the figure, a darker space. It doesn't smell lovely. It's behind and sandwiched between some of the city's tallest buildings. But we had them proceed down out of that, where then they're into a courtyard space. Then they returned to the hotel via a residential area.

Now, one of the things you see here is imagery from a season that is different than which we actually conducted the study. Our first trial study was actually ran in February. Then we also had another iteration ran in October. The February one was run at night and the October one was run during the day.

Just to give you some indication of the pictures at night, this is along that 3rd Avenue stretch with a new Discovery Center that's largely oriented toward children and adult education. Then, this is the alley way view, and we actually had to increase the lighting in the photo because it's a fairly dark place.

Study Site

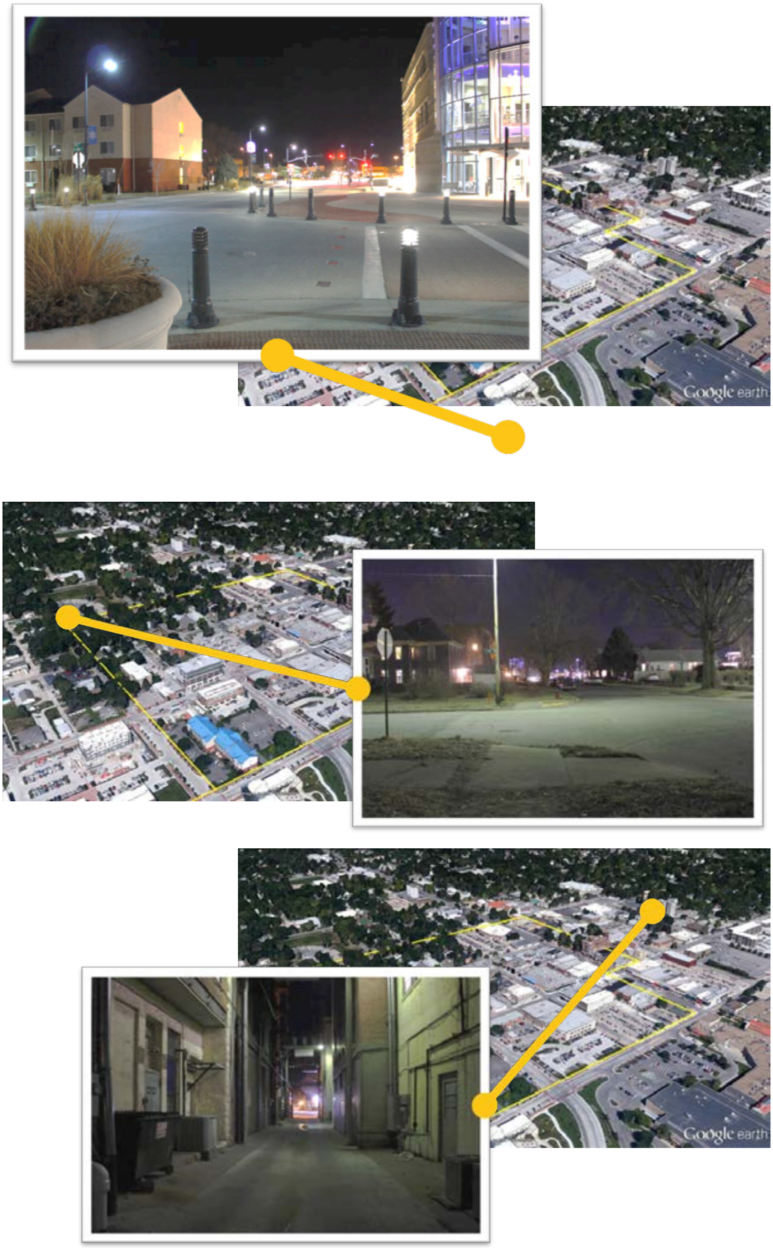


Figure 3.4: Top is at 3rd Avenue. Adjacent the new Discovery Center; middle is the most residntial and landscaped corner of the route; bottom is the alleyway at night, intended to induce some arousel.

Methods + Data Collection

Our approach allowed us to collect a large amount of data, partially because we didn't know exactly what kind of data we wanted initially, and also because we were interested in looking at different machine learning methods that we might be able to tease out various data from.

We wanted to generate similar kinds of data that exists with smart cities, using mobile sensors as a proxy for mobile wristwatches that the masses are now wearing, head-mounted video to gather imagery simulating traffic cameras, et cetera. We also looked at different participant characteristics (biophysical and background) because each person experiences environment in a different way with a different background and context.

However, our aim was primarily on the physiological response, which largely is a subconscious measure in this study. We aimed for the subconscious for two reasons. First, often in many of these studies we gather stated preferences, which means people are having to actively think about what they would evaluate versus us subconsciously collecting that responses as physiological measures.

We also looked at various different sight characteristics in a spatial and temporal context. Additionally, we collected annotations of evaluations in one of our trials. The computer science machine learning literature annotation referes to a technique to elicit as a way where we get either expert-based or participant-based data that so the algorithms can learn what the data says with what individuals say, thereby drawing associations of meaning to the data or identifying anomalies is the stated data on top of this subconscious.

The data came back was analyzed post walk for the individuals, and in other cases for the experts post data analysis, where we could go through and then identify if there was any particular areas where we would see more or less physiological arousal, for instance.

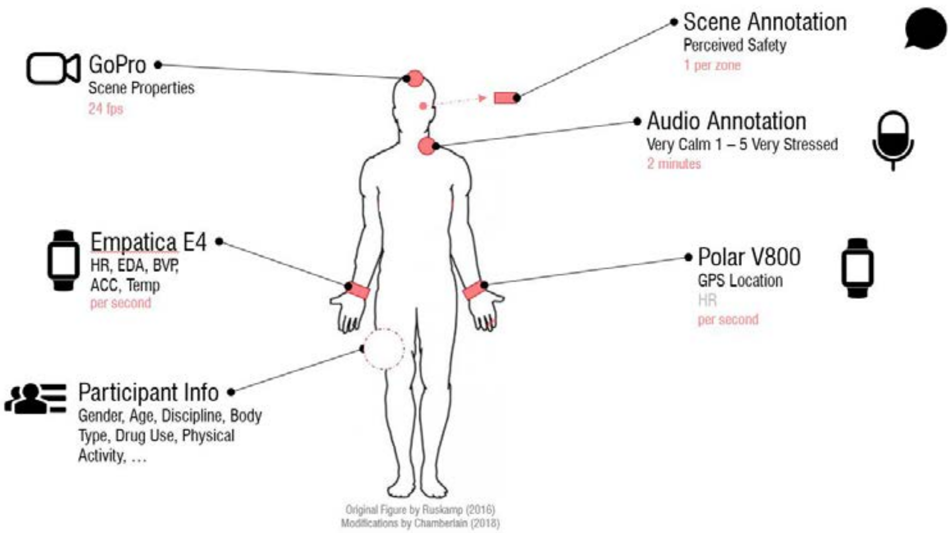


Figure 3.5: diagram showing data obtained from the experiment. Original figure by Rukamp (2016) Modifications by Chamberlain (2018)

Variables:

- *Participant Characteristics*
- *Physiological: (sub)conscious*
- *Site Characteristics*
- *Spatial/temporal*

Annotation:

- *User ratings of perceived safety*
- *Audio rating on comfort/stress*

Figure 3.5 that represents the sensor tools and kind of data we collected. We used different combinations of these tools in different trial experiments. In one experiment we had people walk around with a GoPro. That was at night because there weren't as many people around as there would be during the day. The daytime is difficult, because you're probably, by nature of wearing a GoPro on your head, going to garner some fascinated responses from people, which may effect your physiology just because of the way that they're looking at you.

We haven't actually run much analysis from the GoPro, and I'm not going to be introducing any of that here today. The Empatica E4 is the device that we use for collecting heart rate, EDA, electro dermal response, (galvanic skin response) which I think Bob and Colin will be talking about later, as well as, temperature and accelerometer.

The movement used a Polar V800 watch for the integrated GPS. We did send people out with a phone, but we wanted to collect the GPS data with the wrist watch instead, initially (and partially so we didn't drain the phone's battery quickly since it was an old phone). We also had them use the heart rate for the Polar, but the data was not as consistent with the way that we had set it up, because in the laboratory environment, you typically need to do different kinds of things to collect good data with that.

In trials, we collected audio annotation. This is the second and third iteration of this study where we hooked up a phone that had an automatic timer every two minutes that just had a subtle beeper that went off. The beeper reminded people to state how they were feeling in the space on a scale of one to five, whether very stressed to very comfortable, and give us any reason or rationale for that.

We also collected scene annotation, after completion of the walk. We would show representative slides or images for different areas within the environment, then ask people to provide a perceived level of safety. This is getting at the experience of stress or comfort, of fear or not, in an environment that is a user explained environment outside of the Empatica watch.

The next figure 3.6 is from Taylor's research this past year (2018). She identified sight characteristics using geospatial methods. This is where it gets very interesting for us both in terms of the architectural aspect and the policy aspects. Here we spatially characterize our ideas, what we believe we created, so that may understand how these creations influence people's enjoyment of a space or affective response.

The diagram shows the a route we sent participants along. We put two arrows because in other iterations we actually ran people in both directions. I'm not going to be talking about that either, for sake of time. In this case, we sent people counterclockwise. Notice that we have different spaces where we're indicating grass or shrubs and trees.

We worked hard in this environment, in this location, to try to find different sorts of environmental characteristics. The difficulty in the real world context here is that all of you know that there's a high range of variability in any real world. You might be in a place where there's a lot of trees, the buildings are set back, the lights might not be on, but you have good crosswalk infrastructure.

Figure 3.6: Taylor Whitaker's master's thesis data collection, where applicable, informed by 50 feet radius.

Alternatively, you might have bad crosswalk infrastructure with little trees and the same sort of building context. There are a number of confounding variables in here that make it exceedingly difficult to test this kind of work in a controlled laboratory environment. So, the idea of being able to use a large amount of data from machine learning approach, and collect this over time through different context, is where we're trying to scale this up so that we can start running studies like this in other cities

By developing these mechanisms we may be able to gather other data from devices like Fit Bits and Apple Watches and so forth. We can then start looking at a variety of different environmental characteristics with massive datasets. This just gives an indication just to let you know more as an illustrative rather than something I'm going to work through of different environmental characteristics that exist.

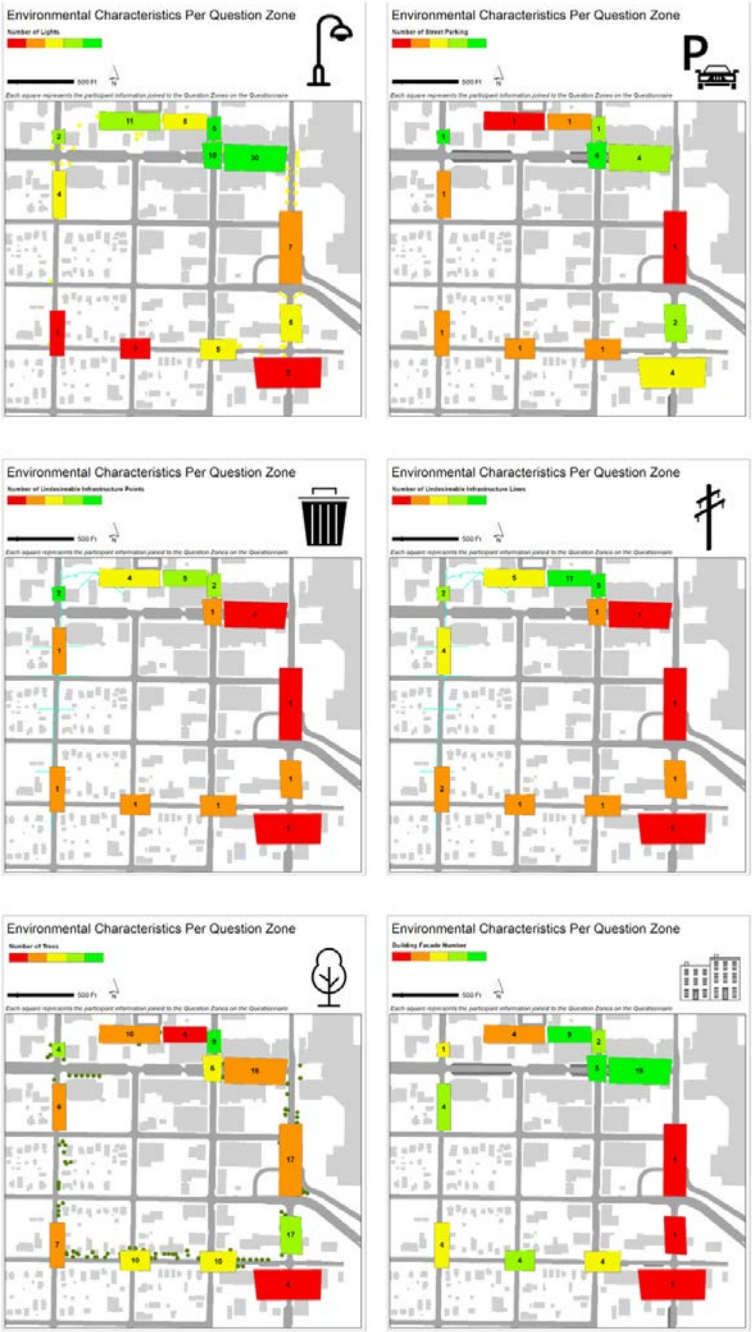


Figure 3.7: Environmental Characteristic Per Question Zone

In the next diagram Figure 3.7, on top left, you see a street lamp. Where we see green, we have a large number of street lamps in any particular zone. For the study we looked both at the real time data, which we collected per second, but we also broke it down to distinctively different zones that we identified as we thought would be different enough from one another.

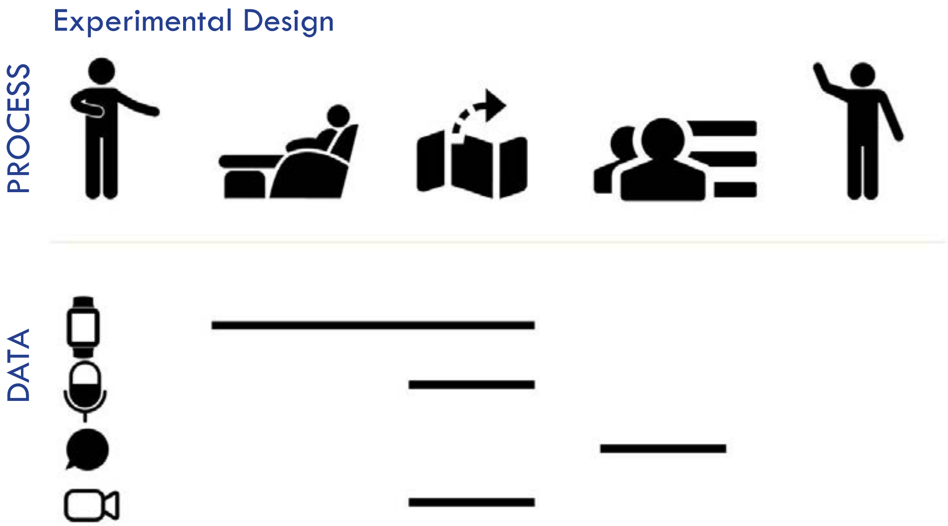


Figure 3.8: Experimental Design Chart.

Notice that on Poyntz Avenue, that large green block where we see 30 lights within that area. It's a well lit space as opposed to the place in the bottom left, the Southwest, which is a residential area where there's one light on that street block.

In Figure 3.7, we can go through that where we've got a number of different parking configurations, trees, buildings, street lamps and other sorts of environmental characteristics. We mapped all of these out and then this is where we can associate those with a different affect of our physiological responses.

The process of the design itself is that we recruited volunteers over different semesters (for different trials). When somebody would come in, we welcome them in, we'd go through the standard consent, we hook them up with the devices for the study and they basically sat there for a while. We collected baseline data from anywhere from four to six minutes.

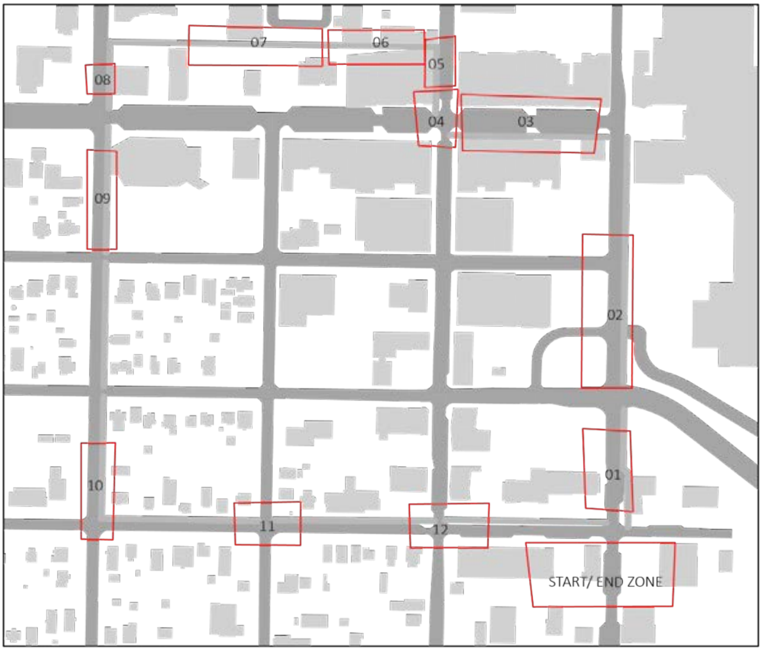


Figure 3.9: Experimental Zone Delineation. 12 zones identified for unique characteristics. Photos taken to represent each, used in scene annotation and aggregated statistics

After that, they went out on a walk that took roughly 20 to 30 minutes that we'd indicated on the map. Then they came back. Then we collected different demographic information and the annotated information of their ratings of perceived safety from different scenes. Then we said thanks and sent them on their way.

Meanwhile, we're collecting the physiological data all the way through walk and the data collection ends when they return to the hotel. In one of the experiments, we collected the audio data just along the walk, as well as GoPro imagery.

Experimental Zone Delineation

In addition to the realtime analysis, we decided to create zones that had distinctive properties. I'm not going to go through all of them for sake of time, but just to give you an idea that we parsed these out where we have areas of high commercial district, so that's one and two, with some variation in the kinds of infrastructure, parking spaces, green spaces around it.

Looking to Figure 3.9; zone 03' is the Poyntz Avenue, a commercial area. Four is an intersection. Five is a space that we identified because it's before they turn down an alley. We're curious to what's happening with people's decision when they're looking at a map, acknowledging that they have to turn down an alley. Are we going to see some kind of response?

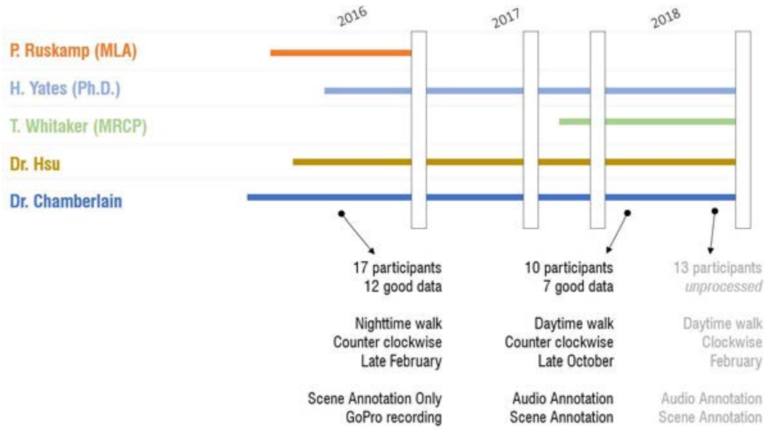


Figure 3.10: Timeline and collaborations for respective projects: Data Collection

The different alleyways in the next zones. We've got one, behind the tall buildings, then a continuation where there's a courtyard and some backend of buildings that are not so lovely. Another district, or another area where we turn and we've got sort of a preparation to cross Poyntz Avenue a large, wide street.

Some combination of residential and commercial, and then down to pure residential. This zone near, 11 and 12, is pretty much residential. Afterwords is the final home stretch returning to the start zone.

As indicated earlier, we conducted three trials (see Figure 3.10). For those of you who are new to this kind of research, it's essential to get a lot of participants not only for statistical reasons, but, because sometimes you don't get clean data.

With the amount of data that we're trying to collect in the various census we're trying to work with, we only ended up with a limited number of good data sets. Here, what I'm going to be showing is a combination of two different studies where sent participants both clockwise and counterclockwise. In February at night and October in the day, Figure 3.11 the kinds of annotation information, as well.

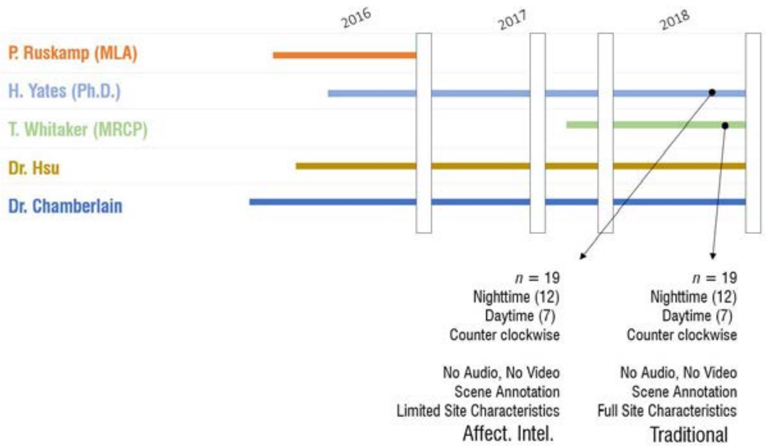


Figure 3.11: Timeline: Data Analysis Runs

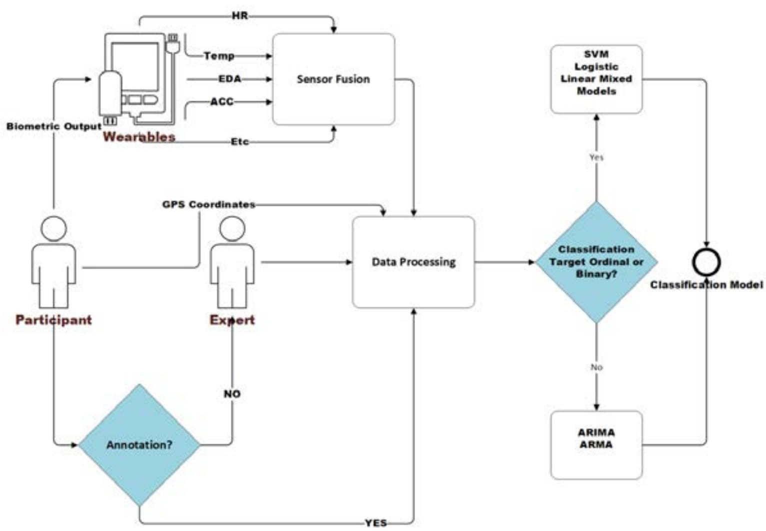


Figure 3.12: Affective Intelligence Framework: Data Classification

Above in Figure 3.12 is the framework published by Heath Yates. The idea is that we took participant's data and analyzed biometric data assoiciated with GPS coordinates. So we basically did a sensor fusion on this where we looked at ways of aggregating and combining data sets that would help us to tease out these environmental affects.

In one case study we actually worked with a colleague in University of Chicago, Greg Norman, who annotated that data to identify from an expert base approach (a publication of this work already exists). After the annotated method, we then asked, "Are there methods, classification targets, that we can look at from machine learning techniques?"

These techniques include support vector machines, logistic, regression, and linear mixed models for those who are interested. Then we have others where we have no or unsupervised classification, a model such as ARIMA and ARMA. Then we look at different models and say, "Can we see if the computer system is able to detect arousal based on the data that exists?"

One of the ways in which we had to normalize the data is to address the baseline physiological data. Often in, neurophysiological work, baseline data is collected so we can identify a standard which to compare by, or correct, or augment by. In this case, what we ended up doing is we had people in the baseline data sitting down and resting. But we were interested in the differentiation when people were walking, relative to a walk with an average heart rate.

We ended up having participants leave the Hilton Hotel and this data analysis that we're looking at is comparing where they started. We indicated the first time they entered a zone and the last time they passed through the zone, much like you would on a 5 or 10k race, where there's some sort of arch. That became our beginning point and our end point that we could then compare data within these different zones with data not in those zones as shown in Figure 3.13.

We have been fortunate to connect with colleague, Dr. Jennifer Healey, who did her Ph.D. at MIT. Jennifer was a student of Rosalind Picard, who is a machine learning faculty member that developed and co-developed the Empatica watch. Dr. Healey had suggested when we look at this kind of data that we need to take care with cleaning the physiological data.

This is because data can get dirty quickly. When you put on a device or shift your wrist quickly, you may get an extreme galvanic skin response because of the way in which that sensor may be integrating or touching with the skin. What we want to do is eliminate some of that extreme data. The proposal was to look at, the median top 10% and the median bottom 10% as base line between the low and high of what somebody would experience in this space shown in Figure 3.14. This is how our physiological data was cleaned and then integrated with GPS data at one second intervals.

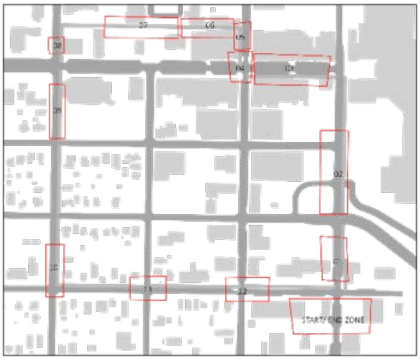


Figure 3.13: Affective Intelligence Framework: Data Normalization. Identify start/stop.

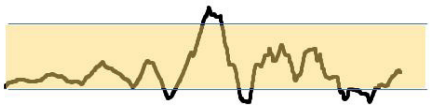
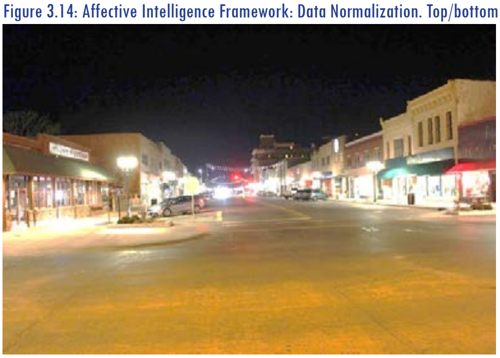


Figure 3.14: Affective Intelligence Framework: Data Normalization. Top/bottom 10% median.



From (Likert): 1 = Very Unsafe. 7 = Very Safe

Figure 3.15: Affective Intelligence Framework: Data Classification

From (Binary): 1-4:1 (Effect), 5-7 (No Effect)

Figure 3.16: Affective Intelligence Framework: Data Classification

The data we have generated is quite complex. One of the ways we're trying to work with this data is to simplify it by starting with a binary approach to determine whether or not we believe that we are seeing arousal or not (or seeing some stress, or some excitement etc.). By simplifying data we can detect anomalies and effects. As we detect these phenomenon we can become smarter determining to what extent are we seeing or detecting nuances of arousal.

From the work that Heath Yates did with Bill Hsu and myself, we separated out several different environmental characteristics.

Participant

- Participant ID
- Normalized HR
- Normalized EDA
- Gender
- Bodyshape
- Urban Origin
- Urban Preference
- Familiarity
- Exercise Regime

Site Characteristics

- Walkability
- # Lights
- # Trees
- # Powerlines
- # Points
- # Grass features
- # Shrubs
- Binary Classification

The full list of characteristics I showed you earlier was not included in this particular analysis of the data. In this instance, we separated participants and their galvanic skin response and heart rate, as well as, some different demographic backgrounds.

One variable you might be interested in was the the urban origin or urban preference. Here we wanted to know if the participant grew up in a rural, suburban, or urban environment and what kind of environment they most associate with now. This helped us understand of familiarity influences people's experience and their level of comfort. We also looked at a few different site characteristics: the number of lights, number of trees in a space, the number of power lines or overhead infrastructure.

Figure 3.17: Traditional Evaluation.
Correlation of Average Electrodermal activity to scene annotation rating on questionnaire: -0.52 ($p < .01$), higher EDA less safe

In this particular method, I just want to show you some indication of where we have data from Taylor Whitaker, who looked at the differentiation between the EDA response and some of these different zones. Figure 3.17. We've just highlighted some of these zones, for instance, during the day. This is an EDA work. When we're seeing a low EDA, it means we're having sort of a low arousal period.

EDA is a very short term measure. A snap of the finger. For instance, if I yelled really loud, or I had my toddler come in and scream unexpectedly, you would likely have a higher EDA response. Over a longer period of time, you would expect to see heart rate going up, as mine does when the screaming happens.

As we progress through this walk through different zones, we actually see a relationship with EDA. We don't know if that's just because of time, or if that really is because of the space until we include time in the analysis as a variable. We were surprised a bit by this because people start out in a commercial area and then end through a residential area. But we suspect, in this case, lighting may have had an effect. It's a suburban environment or a residential environment that, in some cases, could be perceived of being slightly dilapidated. So these may have had effects on peoples' response.

What's interesting here is that when we look at the EDA data, you'll notice a trend showing that the EDA increases similar to what people stated when they were rating scenes that were samples from

Figure 3.18: Traditional Evaluation.
Correlation of Average Heart Rate to Image Rating on Questionnaire: -0.24 ($p < 0.05$). Higher HR, less safe

these particular areas. In essence we see a high negative, or moderately high negative correlation. What that means is as people were having a lower EDA, they were stating that they felt more safe. Which is what we would expect in some regard. A higher EDA, they felt less safe. We also looked at heart rate. Here's an example where we have a few zones. I'm going to highlight the map down in the lower right hand corner.

The zones that are in red are those zones in the back alley. This is exciting, because we know the alley is not a pleasant place to walk. But we were just wondering, could we actually look at this data in a simple respect and ask if we're going to see just some difference in heart rate because of the nature of this place because it is a, dark corridor. In fact, we do see substantially higher heart rate that is statistically significant. What's interesting is that the highest heart rate actually happens from the alley afterwards. Our suspicion of that has to do with the fight or flight characteristic many have heard about. Imagine that you have just walked through this alley and as you emerge you may be more cautious about what is behind you now.

There's a fear that's invoked because of the construction of that environment. It causes us subconsciously and maybe even consciously to consider what's happening and to have our physiology effected by that. Some other things to get out here is that we found the correlation, as I just showed, that was low with heart rate, but moderately high with EDA.

Zone Analysis Results (Questionnaire)

• Correlation between HR and some questionnaire zones.
• Correlation between EDA and some questionnaire zones.

Image Rating Analysis (Questionnaire)

• Medium correlation between the rated images and HR.
• High correlation between the rated images and EDA.

Analysis of Variance (Random Zone)

• Zoning and Heart Rate and EDA.
• Cross Walk Type (stoplight, stop sign, painted) and EDA.
• Correlation between Road Surface Type (asphalt/ concrete) and EDA.
• Speed Limit (mph) and EDA.
• Grass (amount per random zone) and EDA.
• Sidewalk Quality (0-1) and EDA.

When we looked at some different affects, we looked at this analysis of variance, which is a way of identifying what kinds of variables in the environment. So we're seeing things like the crosswalk type; the way in which we construct our crosswalks are going to influence our heart rate, for instance, or galvanic skin response.

The speed limit of the surrounding roads had an effect (we don't know if this is due to cars or the form of the road yet). In this case, we acknowledge that even just the width of the road, the space and the variation that there was likely had some kind of effect. Grass or greenery also had an effect.

Now, when we look at the machine learning techniques, we have several different models that were run. Heath Yates ended up conducting about 60 different machine learning models. That's a herculean effort, for those of you who are not aware of machine learning techniques.

Affective Intelligence: Model Runs

60 Models

- *4 Algorithms*
- *5 Models*
- *3 Validation*

Ran Naïve Algorithms (All + or -)

- *2 Algorithms x 3 Validation*

I'm not going to run through all those, because I didn't necessarily think that was of interest to the audience today. There is a dissertation coming up for those that are very interested in how this works. As a summary, what we're looking here are different coefficients, in this case variables, that we saw as effects related to heart rate and galvanic skin response. We have this walk-ability metric, created by an expert-based approach that defined walk-ability and we are seeing some effect with that.

That interpretation of the expert was found to be well associated with some effect in terms of our physiology. We also saw some effect with lights, trees and the electrical grid overhead, as well as grass.

The power lines and the electrical grid is interesting. We looked at the number of power lines, transformers and power line poles. The results indicated a higher EDA and a higher heart rate because people were within the distance of that infrastructure of roughly, say, about 45% increase in heart rates (though these are preliminary findings).

Now, if you can imagine over an entire population, if your heart rate is that much higher because you're seeing power lines, that might become a public health issue. What is the cost associated with designing that space relative to the cost of having higher heart rate just because of power lines?

This is the kind of work that we're interested in. This is very nascent. I would take these results with a grain of salt, but this expression of the model, which we can look at those different characteristics collecting large data sets, and addressing the different confounding variables is something that is very much of intrigue to designers where we can connect the empirical work to help inform what we do by design, or assess what we do from our designs.

In another case we've got higher heart rate associated with trees, which is surprising because it actually increased our arousal, but it contributed to our stated calmness. We like seeing these kinds of things. We're excited about it.

Summary

Where do we go now? More variables, more data, do we account for noise in the future? We'd love to just have people wear earbuds and then pump through emergency sirens, or these sorts of things to differentiate that kind of effect. We also hope to conduct a temporal longitudinal studies which allow people to these devices over a longer period of this

Coefficient	Estimate	Std. Error	P - Value	
Norm HR	-0.96054	0.13778	3.14e-12	
Norm EDA	0.52031	0.10942	1.98e-06	
Walkability	-0.42300	0.03400	2e-16	Walkable
Num Lights 6	0.55417	0.14641	0.000154	
Num Lights 9	0.96066	0.24840	0.000110	Lights
Num Lights 17	0.62360	0.24744	0.011728	
Num Trees 2	-0.57888	0.12320	2.62e-06	
Num Trees 5	-0.49781	0.11358	1.17e-05	
Num Trees 6	-0.73623	0.11477	1.41e-10	
Num Trees 7	-0.97217	0.13441	4.73e-13	Trees
Num Trees 8	-1.32633	0.16632	1.53e-15	
Num Trees 9	-1.48456	0.15702	2e-16	
Num Tees 10	-2.94440	0.61184	1.49e-06	
Num Lines	0.41176	0.02682	2e-16	Electrical Grid
Num Points	0.22438	0.07942	0.004728	
Num Grass 1	0.62416	0.08694	7.00e-13	
Num Grass 2	1.47801	0.10110	2e-16	
Num Grass 3	2.86276	0.11734	2e-16	Grass
Num Grass 4	2.81924	0.15745	2e-16	
Num Grass 5	2.52025	0.43669	7.87e-09	
Num Grass 6	2.98681	0.54243	3.66e-08	

Figure 3.19: Affective Intelligence: statistically significant coefficients

time.

We also want to look at different annotation modalities. So, whether that's looking at facial recognition, or collecting more audio, or visual kind of data, so that we could walk through and classify by an image technique the different kinds of infrastructure that somebody would see in a given space.

Next Steps

One of the things that I had mentioned here is that we're looking at these different environmental characteristics. But the question is: how do we characterize those? There's a lot of work that says a variety of facades is wonderful. Having trees is fantastic. Having well designed lights and variation in building heights, people enjoy. But how do we actually express that spatially? Is that experienced right in front of you? 20 feet in front of you? 100 feet in front of you? Through time?

How do we actually amalgamate that information understand how that affects our perception? While there's a lot of books written about this work, the precise way in which we would characterize or evaluate this is less known. That's something that we're looking at with these spatial models. In the future, we will try to create these different variations and work these through these machine learning techniques to see if there's any functional difference.

There's several open questions here. Can affective computing allow us to teach machines to learn from peoples' responses, their physiological response both as classified or supervised, where we annotate or unsupervised just as the subconscious?

- *Can affective computing allow us a way to teach machines to understand the complex interactions between environmental characteristics social interactions?*
- *Does affective computing approach offer additional insights that traditional research methods for studying built environments have not addressed?*
- *What are the additional biographical information which may serve useful in building a more nuanced and generalized model?*
- *How can models be evolved to detect affect and contextual affect beyond arousal?*

Can this help augment, or does it differentiate really from more traditional methods? Linear regression or analysis of variance. How is it that we can look at different biographic information from individuals and also assess more of the architectural realms? That's where, for me, as a non-formally trained designer, would benefit greatly from working with designers who are more sensitive to the variations of urban fabric and urban design, to depict and characterize these differences.

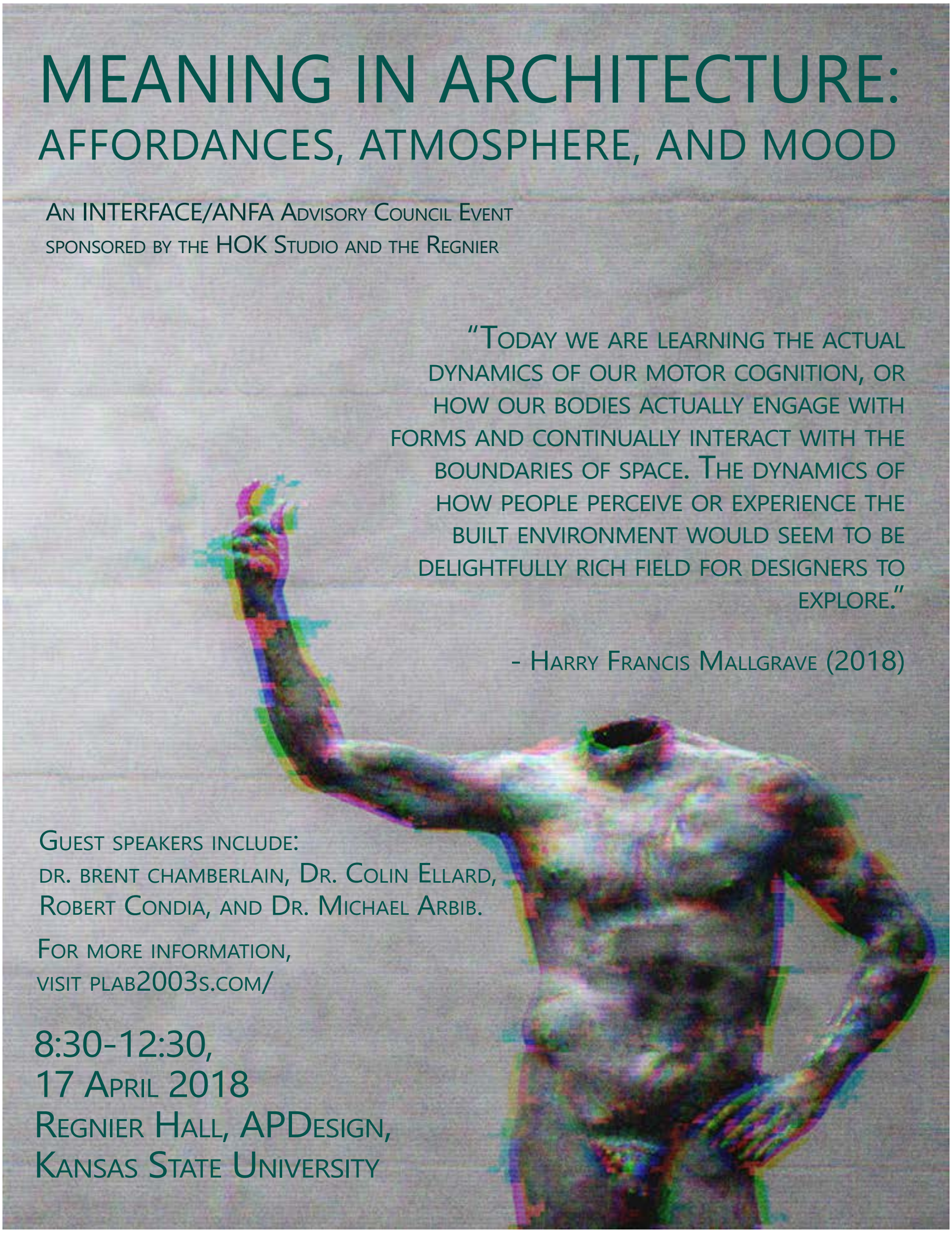
As I conclude with this work, I want to again offer my sincere thanks to Dr. Hsu, and Heath Yates. Additionally, I want to thank Katie

Heinrich from kinesiology and Professor Condia, who was on Parker Ruskamp's initial committee, Greg Newmark, who was on Taylor's committee, Professor Bai from Eastern Washington University, Greg Norman from University of Chicago and Professor Song from statistics at K-State.

All results provided in this discussion are preliminary. Prior and upcoming publications stemming from this work contain the best and vetted results.

Additional Readings

- *Yates, H., Chamberlain, B., & Hsu, W. H. (2017, October). A spatially explicit classification model for affective computing in built environments. In Affective Computing and Intelligent Interaction Workshops and Demos (ACIIW), 2017 Seventh International Conference on (pp. 100-104). IEEE.*
- *Yates, H., Chamberlain, B., Norman, G., & Hsu, W. H. (2017, September). Arousal Detection for Biometric Data in Built Environments using Machine Learning. In IJCAI 2017 Workshop on Artificial Intelligence in Affective Computing (pp. 58-72).*
- *Yates, H., Chamberlain, B., & Hsu, W.H. (2018, April). Binary Classification of Arousal in Built Environments using Machine Learning. Under Review In IJCAI 2018 Workshop on Artificial Intelligence in Affective Computing.*


MEANING IN ARCHITECTURE:
AFFORDANCES, ATMOSPHERE, AND MOOD
An INTERFACE/ANFA Advisory Council Event
sponsored by the HOK Studio and the Regnier
"Today we are learning the actual dynamics of our motor cognition, or how our bodies actually engage with forms and continually interact with the boundaries of space. The dynamics of how people perceive or experience the built environment would seem to be delightfully rich field for designers to explore."
- Harry Francis Mallgrave (2018)
Guest speakers include:
dr. brent chamberlain, Dr. Colin Ellard, Robert Condia, and Dr. Michael Arbib.
For more information, visit plab2003s.com/
8:30-12:30,
17 April 2018
Regnier Hall, APDesign,
Kansas State University

Bob Condia, Symposium Instigator and Managing Editor

Postscript

Recent advances in the biological sciences confirm many of the architect's expert bias in how people are in space, while opening new doors to understanding perception holistically within our experience of architecture and urban design. "Meaning In Architecture: Affordances, Atmosphere and Mood," first shared on these objectives as a public conversation about human awareness of building, specifically speaking to the significance of affordances, embodied simulation theory, atmosphere and mood. It is herewith presented in copy form for broader distribution. An exchange between scientists and architects, this symposium was the inaugural Interfaces event of ANFA (the Academy of Neuroscience for Architecture, Salk Institute) held 17 April 2018 in the Regnier Forum of APDesign, Kansas State University. Instituted by the ANFA Advisory Council under the advice of the ANFA Board, this was the first ANFA sanctioned event outside La Jolla. The occasion was sponsored by the Regnier Chair in Architectural Research, the HOK Studio and APDesign.

How can we measure ourselves into space? How can we get genuine data in the cluttered circumstances of the real world? The morning began with Dr. Brent Chamberlain, (now an LAEP Assistant Professor at Utah State) presenting "The Physio-Affective Built-Environment," exploring new methods for collecting data of the body in space. His research into perception combines computer graphics, geo-visualization, information visualization, and GIScience to conduct scientific inquiry and understanding. Brent's multidisciplinary background in computing, ecosystem modelling and environmental psychology pushes the boundaries of science in perception of urban and natural environments. Specifically, his work explores the potential of a wearables and sensors centric approach for collecting data in built environments. These studies demonstrate the viability of measuring physiometric (arousal indicators), such as heart rate, in urban environments. Especially significant is the aim to develop machine-learning approaches to classify sensor inputs based on annotated arousal output as a target. These results are used as a foundation for designing and implementing an affective intelligent systems framework for arousal-state detection via supervised learning and classification. It seems we can in fact measure results in the real world.

It is well known that vision splits between central vison, the what stream in the brain, and peripheral (the rest of the visual field) as the where stream. What this split in vison has to do with our experience of urban space has not been studied. Until now, Dr. Colin Ellard and I showed a study from his lab, "Place, Peripheral Vision, and Space Perception: a pilot study in VR." The presentation was unfortunately complicated as Coilin was stranded in Toronto because of severe winter storm and was only virtually present. Not a problem in this present medium. We report the consequences of central and peripheral vision in urban plazas of classical and modern articulation. The single most important outcome of this experiment was the dramatic demonstration of the prepotent power of the visual periphery for the generation of architectural experience. Central vison, what most people think of as vision, has little to do with how we experience an urban square in VR.

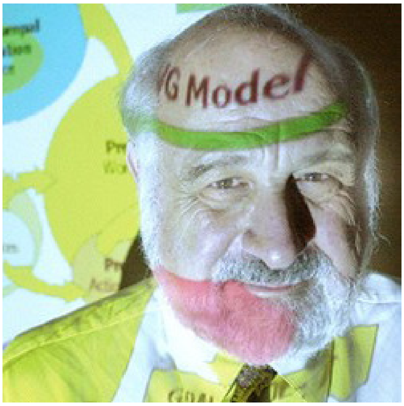
"What goes on in the brain of architects designing a building, or in the brains of people experiencing architecture?" asks Dr. Michael Arbib, whose keynote "It Takes More Than A Hippocampus To Build A Cognitive Map" included remarks on cognitive maps in blind people before offering what neuroscience might teach architects. Dr. Arbib is a pioneer in the interdisciplinary study of artificial intelligence, neuroscience and computation, the thrust of his work is expressed in the title of his first book, Brains, Machines and Mathematics (McGraw-Hill, 1964) which encompasses the notion that the brain is not a computer in the current technological sense, but we can learn much about machines from studying brains, and much about brains from studying machines. The two important lessons I take from his talk are: Space as we perceive it always means motion, eye and physical as we are always adjusting our mental constructions of our surroundings; and, one's cognition of their surroundings is necessarily informed by the biology of our brain-body (machine) as a singular unit of measure. What you expect of a place has much to do with wat it can afford you.

The final act was Dr. Kevin Rooney moderating our speakers in panel discussion, "How Architects can talk to Neuroscientists: How

Neuroscientists can talk to Architects." Although we had anticipated this as its own chapter in this volume, we have instead folded the comments into the papers each.

In acknowledgement let me extend our gratitude to Victor Regnier for his continued support to the Department of Architecture's Regnier Chair for Research; to HOK Architects (especially the Kansas City Office) for their support of a thesis design studio based in the neuroscience in architecture debate. A particular thanks goes to Michael Arbib's construction of the ANFA Advisory Board, challenging the community of architects and scientists to spread our conversation outside La Jolla and more regularly than biannually. My personal gratitude goes the fine staff of P\Lab2003s: Shea Ensor, Marilina Bedros, Dakota Smith, Jaasiel Duarte-Terrazas, and Alexandra Mesias in organizing the details and staffing the event. A special appreciation goes to Vatsel Patel who edited the video presentations into a very legible production. To Professor Matt Knox in some fine video collection and the sharp audio feed. Acknowledgements to the ANFA Board for allowing us to carry their good name, particularly Frederick Marks and Matthew Smith. And irrevocably to the Michael, Brent, Kevin and Colin for their contributions to this symposium and advancing the oratory of neuroscience in architecture to far-reaching advantage.

Biographies



Dr. Michael Arbib

Dr. Arbib is currently an Adjunct Professor of Psychology at the University of California at San Diego and a Contributing Faculty Member at the NewSchool of Architecture and Design in San Diego. After serving on the ANFA Board of Directors, including Vice-President, he now leads the ANFA Advisory Council. Michael is currently writing a book on the bond between neuroscience and architecture.

Robert Condia, FAIA

Bob Condia, FAIA, is an architect and design partner with Condia+Ornelas Architects, and the 2017-20 Regnier Chair of Architecture.

A Professor of Architecture, he teaches architecture as an art form with due considerations to neuroscience and a biological basis of aesthetic experience. Member of the ANFA Advisory Council

Dr. Colin Ellard

Dr. Colin Ellard is a professor of psychology, specializing in cognitive neuroscience, at the University of Waterloo in Canada. Dr. Ellard is particularly interested in the emotional effects of architectural settings, which he explores in both field settings and in synthetic environments using immersive virtual reality. Dr. Ellard's work focuses on emotional and cognitive effects of built settings, using both field or laboratory approaches. Member of the ANFA Advisory Council

Dr. Brent Chamberlain

Dr. Brent Chamberlain, (Assistant Professor of Landscape Architecture Regional and Community Planning, KSU). Director of the Advanced Landscape Immersion and Visualization Environment (ALIVE!), his research combines computer graphics, geo-visualization, information visualization, and GIScience to conduct scientific inquiry and understanding.