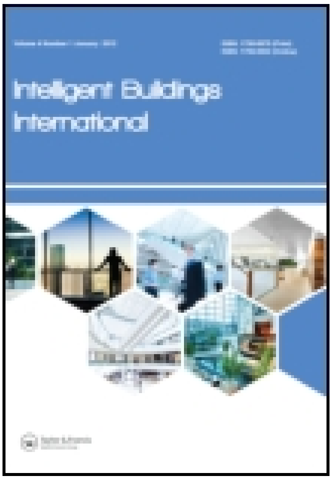

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Lessons from neuroscience: form follows function, emotions follow form

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RESEARCH ARTICLE

Lessons from neuroscience: form follows function, emotions follow form

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The argument that the environment impacts human perception and behaviour, and vice versa, is not a new one. What is lacking however is a fine-grained, deep understanding of the neural underpinnings that drive human behaviour as a result of environmental interaction. The challenge of simulating three-dimensional environments while mapping brain behaviour (which is still a rather confined activity) has made this initiative daunting. In this article, we argue that a common unit between architectural environments and functional magnetic resonance imaging (fMRI) experiments is 'the visual image'. Architecture relies on visual stimuli to conceive, design, present, and even experience environments. fMRI experiments use visual stimuli to induce desired cognitive and emotional states to study the neural underpinnings. Although a wealth of evidence exists in the field of environmental psychology and psychophysiology on how visual images, specifically nature content in visual images, can reduce the negative emotions of fear, pain and anxiety-aiding restoration to a positive state, it is not clear, however, which specific visual properties contribute to this effect. If the specific visual properties could be isolated and correlated to specific emotional response, they could serve as the building blocks for designing not just for functions a design supports, but also the emotions it invokes. In this article we look at the emotional impact of visual stimuli, and bridge the evidence between environmental psychology and neuroscience, within the scope of nature images, to identify specific visual properties that (may) elicit emotional responses. We then investigate a particular visual property 'contours' and explore it within the theoretical paradigm of neuro-architecture to generate specific hypotheses for architecture and neuroscience. Finally, we take the discourse to architecture and explore the relevance of the subject of form, especially rapid emotional response to form, elicited by the specific property of contours.

Keywords: aesthetics; environment and behaviour; evidence-based design; user experience design

Introduction

In this article we look at the emotional impact of visual stimuli and bridge the evidence between environmental psychology and neuroscience, within the scope of nature images, to identify specific visual properties that elicit the emotional responses of fear, pain, and anxiety – emotions that are prevalent in high stress environments such as hospitals – which architects and designers work hard to mitigate. We then investigate a particular visual property 'contours', emergent from the literature, and explore it within the theoretical paradigm of neuro-architecture to generate specific hypotheses for architecture and neuroscience. The impetus for this article came from research into how (and why) visual images of nature have a positive impact on stress and anxiety, particularly in the healthcare context (see Nanda et al. 2012). In probing deeper into

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the issue we found that the impact of nature images may be linked to specific visual properties, an insight that is applicable to the broader design industry, ranging all the way from product design to building design and architecture.

In '*Nesting, Body, Dwelling, Mind*', Robinson (2011) argues that our very being is sculpted by our interactions in an environment that we ourselves have fashioned, making us our own greatest artefact. Environments are important, in large part, because of the experiences (and behaviours) they afford. Gibson (1979) argued that the measure of potential interactions between an organism and its immediate environment can be understood as its 'affordance'. When as designers and architects we seek to sculpt not just spaces, but human experience and behaviour, we are designing more than environments, we are designing affordances. In addition, we can argue that these affordances are not just functional but can be emotional as well. Functional affordances would relate to the measure of potential interactions between an organism and its immediate environment, that relate to a specific function. Emotional affordance on the other hand might be the measure of potential emotions triggered by an environment in an organism. In design, emotional and functional affordances go hand in hand, but the latter is arguably easier to assess than the former.

Traditionally, environmental psychology has focused on the study of obvious manifestations of human behaviour, which in turn has been linked to hypothesized thought processes. Typical tools used include systematic or ethnographic observations, surveys, interviews, psychometric instruments (such as self-reports on emotional states), physiological measures (such as heart rate, blood pressure, etc.), and cognitive tests (based on the performance on cognitive tasks measured by careful calibration). Over time, these tools have become sophisticated, and insights into human behaviour more detailed. Researchers have come to a general or common understanding on the cognitive and emotional systems involved, based entirely on inferences from observed behaviour, which make it subject to interpretation. Further investigation through neuroscience, of topics that already have a body of evidence in environmental psychology, offers the opportunity for a more objective understanding that can take us beyond the 'what happens' to the 'why it happens', and allow a more sophisticated use of science within design practice. This may be the first step in investigating what Eberhard in his fundamental work on *Brain Landscapes* calls 'the ways and whys of our brain/mind interaction with architectural settings' (Eberhard 2008).

According to Garland (2004), neuroscience is 'the branch of the life sciences that studies the brain and nervous system including brain processes such as sensation, perception, learning, memory, and movement'. Among the areas of study, included under the broadest definition, are physiology, chemistry, and molecular biology of the nervous system; issues of brain development; brain processes such as sensation, perception, learning, memory, and movement; and neurological and psychiatric disorders. Studies of the brain often involve the study of a response to an external stimulus and broadly we can define anything outside the human body as the environment. In the case of design and architecture intentional crafting of this environment is 'environmental design', and study of the human response is environmental psychology. Neuroscience studies have taken mainstream psychology to the next level, and now offer an opportunity to do the same with environmental psychology. There is an opportunity to test the theories and conceptual constructs that are in place and investigate the extent to which they hold true at the level of brain behaviour. In addition, neuroscience offers the opportunity to create new hypotheses for the environmental design field which have not been tested due to lack of sophisticated tools, such as functional magnetic resonance imaging (fMRI).

If we define the role of an architect as a person who not only designs environments, but also designs affordances, manifested (and tested) by brain response, then the discussion about neuroscience and architecture reaches an entirely different level. Edelstein (2006) proposes that the role of the architect is that of a designer of environments that can stimulate brain responses (activity, novelty, and memory). Understanding the mechanisms of neuroscience can, potentially, help maximize the desired positive impact of a designed environment. In addition, an understanding of the mechanisms of neuroscience, particularly in the area of perception and spatial orientation, can inform the design of built spaces to include environmental considerations that minimize negative physiological, cognitive, and emotional effects (Sternberg and Wilson 2006). In certain settings, such as healthcare, minimizing negative effects may be even more crucial than maximizing positive effects. Sternberg gives examples of how an understanding of fine-tuned principles of perception (gleaned by neuroscience studies) inform pragmatic insights into design – for instance, poor lighting renders edges difficult to recognize, or how presence of multiple choice points in the absence of visual cues can trigger anxiety and a stress response (Sternberg and Wilson 2006). Based on a review of the literature she identifies environmental stressors such as crowding, sudden loud noise, bright lights, multiple choices, lack of landmarks, and being in a new environment, and argues that exposure to such stressors can activate both the hypothalamic–pituitary–adrenal axis and the adrenergic component of the autonomic nervous system. An understanding of how our perceptual systems work is particularly critical within the context of healthcare where all the users of the environment – patients, visitors, and staff members – are anxious and stressed and are in highly vulnerable emotional states. Moreover, healthcare is currently the leading A/E sector in evidence-informed design, making this a critical sector for scientific discovery in design research.

The term ‘healing environments’ has been used often in the last few years (Sternberg 2006) to create environments that ‘afford’ more positive responses and interactions. The term ‘healing environments’ suggests ‘that the physical healthcare environment can make a difference in how quickly the patient recovers from or adapts to specific acute and chronic conditions’ (Stichler 2001). Evidence-based design has taken root firmly in the healthcare design industry, defined as ‘the process of basing decisions about the built environment on credible research to achieve the best possible outcomes’ (Levin 2008). A case in point where design is being informed by science is the infusion of nature images in healthcare setting.

Images and their emotional impact: making the case for nature images

While there is a plethora of research from environmental psychology that links viewing visual scenes/images to observed/reported/measured behaviour, the neural underpinnings are not completely known. In a landmark study published in 1984, Ulrich found that post-operative gallbladder surgery patients whose rooms had a window view of a park had better outcomes than those patients whose rooms had a window view of a brick wall. Patients complained less to staff, needed analgesic pain medication of lesser strength, and were discharged earlier (Ulrich 1984). This study prompted various studies on the impact of nature, both real and simulated. Today, a mounting body of evidence makes the case for the role of nature images in reducing stress, anxiety, pain perception, and improved perception of quality of care (Ulrich 2009; Hathorn and Nanda 2008). Experimental studies on this subject have used nature stimuli of various modalities: two-dimensional art, videos, backlit ceiling/wall-mounted images, and virtual reality (VR) (Hathorn and Nanda 2008). A study with mental health patients found that viewing visual art depicting a landscape (Figure 1) decreased patient aggression and agitation, measured by the rate of ‘as-needed’ medication dispensed to the patients, a finding with significant cost saving implications for the hospital (Nanda et al. 2011). In another study, heart rate measurements, collected in a dental clinic, found patients experienced lower stress and anxiety on days that a large mural depicting a natural scene was hung on the waiting room wall (Heerwagen and Orians 1990). Heart surgery patients in the intensive care unit had their recovery

Figure 1. Nature landscape used in Nanda et al. (2011).

outcomes compared across six groups of patients assigned to different picture exposures. Patients exposed to a representational, nature image experienced less postoperative anxiety and fewer doses of strong pain medication, as compared with patients exposed to no art, or abstract art with rectilinear forms – which in fact worsened the outcomes (Ulrich, Lunden, and Eltinge 1993).

A study by Pati and Nanda (2011) reported improved attention and overall calm behaviour in paediatric patients waiting in dental and cardiac clinics when children were exposed to nature-themed videos. A nature video also resulted in a significant decrease in reported pain intensity, pain quality, and anxiety by burn patients (Miller, Hickman, and Lemasters 1992). Nanda et al. (2012) found that adult visitors and patients visiting an emergency department waiting area exhibited significantly less restless behaviours (pacing, getting out of seat, fidgeting, etc.) and were quieter, after a nature video and nature art was installed. In a 2002 study at the Hong Kong Polytechnic University, researchers found that there was a significant increase in pain threshold and pain tolerance when a soundless nature video was used (Tse et al. 2002). Adult patients in a procedure room reported better pain control when exposed to a nature scene with nature sound in the ceiling (Diette et al. 2003). In an earlier study, patients on gurneys viewing ceiling-mounted scenes of nature and/or water had systolic blood pressure levels 10–15 points lower than patients exposed to either aesthetically pleasing 'arousing' pictures or a control condition of no picture (Coss 1990). In a recent study with backlit images on a wall, Vincent et al. (2010) found that nature images that depicted a balance of prospect and refuge elements significantly reduced the sensory perception of pain. Breast cancer patients reported reduced anxiety during chemotherapy when exposed to VR intervention displaying underwater scenes (Schneider et al. 2003). A similar finding was made when patients were asked to enter a virtual environment by playing video games or wearing a headset (Hoffman et al. 2001). Physiological data collected via skin conductance, muscle tension, and pulse transit time from subjects who watched photographic simulations of natural settings showed faster recovery than subjects who viewed simulated urban settings

(Ulrich et al. 1991). The studies discussed above have prompted the use of nature as a 'healing' or 'restorative' component in environments. A positive change in (physiological) activity that takes place within 4–40 minutes is called 'restoration' and the environments that induce these changes are called 'restorative environments' (Korpela, Klemettila, and Hietanen 2002). In many of the studies outlined above, the physiological response has been rapid, synced in real time to the exposure to nature images, and measurable, making the argument that particular kinds of images – nature images with specific characteristics of depth of field, verdant vegetation, clear focal points etc. – are restorative (Ulrich 2009). However, designers are still working to identify the specific elements that create this 'restoration effect', in order to intentionally create such experiences. One of the underlying theories explaining the impact of nature images is the 'Evolutionary Theory' – that we as a human species are hardwired to prefer and respond positively to nature images that foster wellbeing and survival (Ulrich 2009). This theory and the rapid physiological response suggest that the response to nature at some level is primal, basic, and innate to us all.

Zajonc (1980) argues that at the core of our human survival we often use a quick, pre-cognitive, rapid assessment of the environment based on some gross elements of the image which is insufficient for cognitive judgements but are adequate for an initial approach or avoidance decision. This approach or avoidance decision is also known as the fight or flight response. The 'fight or flight response' is our body's primitive, automatic, inborn response that prepares the body to 'fight' or 'flee' from perceived attack, harm, or threat to our survival. When we experience excessive stress whether from internal worry or external circumstance, a bodily reaction is triggered called the 'fight or flight' response. This response actually corresponds to an area of our brain called the hypothalamus, which when stimulated initiates a sequence of nerve cell firing and chemical release – chemicals like adrenaline, noradrenaline, and cortisol are released into the bloodstream – that prepares our body for running or fighting. These patterns of nerve cell firing and chemical release cause our body to undergo a series of very dramatic changes and when our fight or flight system is activated, we tend to perceive everything in our environment as a possible threat to our survival. By its very nature, the fight or flight system bypasses our rational mind – where our more well thought out beliefs exist – and moves us into 'attack' mode (Neil 2013). It is the key to the context of stressful environments because it adds to the stress response. The theory of a rapid affective evaluation of the environment has been supported by the outcome studies discussed in the previous paragraphs. Research by Korpela, Klemettila, and Hietanen (2002) establishes that rapid evaluation of environmental scenes also modulate people's judgement of human expression (such as joy and anger).

Having the ability to rapidly assess the environment is arguably at the core of human survival and evolution. Research shows that humans have the ability to capture the 'gist' of a scene very quickly. For example, after presenting a photograph for just a fraction of a second, an observer may report that it is an indoor kitchen scene with numerous colourful objects on the countertop (Potter 1975; Biederman, Mezzanotte, and Rabinowitz 1982; Tversky and Hemenway 1983; Oliva and Schyns 1997). Such report at a first glance (brief exposures of 100 ms or below) onto an image is remarkable considering that it summarizes the quintessential characteristics of an image, a process previously expected to require much analysis such as general semantic attributes (e.g. indoors, outdoors, office, and kitchen), recognition of places with a restricted spatial layout (Epstein et al. 1999), and a coarse evaluation of distribution of visual features (e.g. highly colourful, grayscale, several large masses, and many small objects) (Sanocki and Epstein 1997; Rensink 2000).

Do we really respond to visual images and by extension our visual environments even before we completely recognize what they are? Is this response dictated by content or form? Since all images have a combination of both, a designer might also pose the question, if content stayed the same – could form alone impact our rapid emotional response? And if so, could the same be argued for utilitarian artefacts – e.g. kitchen products, furniture, and buildings – that function remaining the same, the form alone can 'trigger' a rapid response. While it is possible to study the response to different environmental design conditions with more traditional observation methods, neuroscience alone has the ability to identify the initial, rapid response – after all it is the response in the brain that is manifested in the physiological and behavioural responses. In this article our intention is to take the insights from neuroscience, and distill them into ideas for design beyond the scope of the visual scene. The focus in this article is on the 'rapid' response, the initial, arguably pre-cognitive response that could shape emotional affordance of an environment.

Towards this end a literature review was undertaken that looked at the neural underpinnings of negative emotional states (pain, fear, and anxiety), induced by visual image properties (Nanda, Zhu, and Jansen 2011). The context of the literature review was healthcare environments, where, as discussed before, minimizing negative impact on vulnerable populations takes priority over maximizing positive impact. The purpose of this grant-funded literature review (funded by the Center for Health Design) was a more fine-grained understanding of how visual images could impact the emotional experience patients are likely to experience in a hospital emergency department. According to Gordon, Sheppard, and Anaf (2010), it is common to 'feel' fear, anxiety, and pain in a hospital setting. Although these emotions are certainly not an exhaustive list of what a patient can experience in a healthcare setting, they helped create a road map for how to navigate the neuroscience literature. The intention of the literature review was to advance the knowledge base in the current practice of infusing nature into healthcare settings. In addition, the purpose of the literature review was to isolate 'specific properties' and match them to specific emotional states, to enable extending these insights to the broader context of design. In the next section, we will discuss some 'form'-based findings from this review (published elsewhere).

Beyond content – to form

Neuroscience studies that use visual images as stimuli to induce fear, anxiety, or pain were reviewed by Nanda, Zhu, and Jansen (2011) to gain an understanding of specific visual characteristics/properties that induce negative emotional states. All studies reviewed used visual stimuli to induce specific emotional states, or identified an emotional salience in the brain area activated in response to the image. All studies used fMRI . A complete review of the articles is available in Nanda et al. (2012), and complete matrix of articles is available for downloading at http://www.healthdesign.org/sites/default/files/chd408_researchreportvisualart_final_0.pdf.

The following visual characteristics were identified by Nanda, Zhu, and Jansen (2011), which directly affect brain behaviour linked to the emotional state of anxiety, fear, or pain: (1) valence and arousal, (2) ambiguity, (3) familiarity and novelty, (4) spatial frequency, and (5) contour. A preponderance of evidence discussed the affective properties of the content, showing how fear, anxiety, and pain could be triggered by the valence (pleasant/positive to unpleasant/negative) and the *arousal* (calming/soothing to exciting/agitating) in the content. In addition, familiarity and novelty were identified as properties that affected the emotional response. The most common system used for categorizing emotional content and using images as 'emotional probes" to trigger an emotional response was the IAPS (International Affective Picture System) (Britton et al. 2006). The IAPS provides access to more than 1000 images that have been rated based on a series of experiments along emotional dimensions (valence, arousal, and dominance). Pictures available include depictions of mutilations, snakes, insects, attack scenes, accidents, contamination, illness, loss, pollution, puppies, babies, and landscape scenes, among others that are often used to induce emotional states (Lang, Bradley, and Cuthbert 1997). Table 1 shows some

Table 1. Shortlisted neuroscience articles.

Article		Emotion			Visual stimuli/visual property	Brain region(s)
No.	References	Fear	Anxiety	Pain		
1	Irwin et al. (1996)	X			Facial expressions and scenes	Amygdala is activated for involuntary affective behaviour such as conditioned fear response.
2	Whalen et al. (1998)	X			Facial expression	Amygdala activation was observed in response to masked fearful faces vs. masked happy target faces.
3	Vuilleumier et al. (2003)	X			Facial expression	Neural responses in fusiform cortex, and effects of repeating the same face identity upon fusiform activity, were greater with intact or high-spatial-frequency face stimuli than with LSF faces, regardless of emotional expression. In contrast, amygdala responses to fearful expressions were greater for intact or LSF faces than for HSF faces.
4	Whalen et al. (2001)	X			Facial expression	Activity in the amygdala was greater to fearful facial expressions compared with neutral or angry faces.
5	Britton et al. (2006)	X	X		Facial expressions, evocative scenes	Both faces and IAPS pictures activated similar structures, including the amygdala, posterior hippocampus, ventromedial prefrontal cortex, and visual cortex. In addition, expressive faces uniquely activated the superior temporal gyrus, insula, and anterior cingulate more than IAPS pictures, despite the faces being less arousing. For the most part, these regions were activated in response to all specific emotions; however, some regions responded only to a subset.
6	Chiao et al. (2008)	X			Facial expressions	Amygdala responsivity increased when fear was detected in members of one's own culture relative to other cultural groups.
7	Ongur et al. (2005)				Pentagon or ellipsoid shapes, previously seen and novel visual stimuli	Found significantly greater activation of the right hippocampus when discriminating previously seen compared with novel pairs of visual stimuli.

(*Continued*)

Table 1. Continued.

Article		Emotion			Visual stimuli/visual property	Brain region(s)
No.	References	Fear	Anxiety	Pain		
8	Bar and Neta (2007)	X			Objects, patterns, contour, spatial frequency	The amygdala was more active for everyday sharp objects compared with their curved contour counterparts.
9	Onoda et al. (2008)		X		Positive and negative pictures	During anticipation of pictures with certain negative valence, activities of supracallosal anterior cingulate cortex, ventrolateral prefrontal cortex, insula, and amygdala were enhanced relative of activity levels that for the uncertain emotional anticipation condition.
10	Roy et al. (2009)			X	Positive and negative pictures	Emotions induced by pleasant or unpleasant pictures modulated the responses to painful electrical stimulations in the right insula, paracentral lobule, parahippocampal gyrus, thalamus, and amygdala.
11	Anders et al. (2008)	X			Humans or animals pictures	The amygdala responded to both negative and positive stimuli, and this response did not increase with arousal. In contrast, thalamic and cortical activity increased with arousal.
12	Weierich et al. (2010)				Pictures with different arousal, valence, and novelty	Compared with negative (vs. positive) and high (vs. low) arousal stimuli, the amygdala had higher peak responses and a selectively longer time course of activation to novel (vs. familiar) stimuli.

of the key articles on the effect of content-based properties on specific regions of the brain. The *amygdala* was identified as one of the key regions of the brain involved in the processing of fear, anxiety, and pain (induced by visual images). The amygdala is part of the limbic system that is connected to various cortical and subcortical brain centres, with a fundamental function of providing neutral stimuli with positive or negative values through association learning (LeDoux 1996). The amygdala is an almond-shaped cluster located in the medial temporal lobe. It is critical to fear-related emotional processing or stimulus salience. Other areas associated with anxiety, fear, and pain processing included the thalamus, insula, and hippocampus. The insula is located in the cerebral cortex, between the temporal and frontal lobe. It regulates physiological responses such as heart rate or blood pressure and produces an emotional context for convergent (sensory) information. Also, it plays a role in the experience of pain, and emotion of anger, fear, disgust, and happiness. The thalamus is located between the cerebral cortex and the midbrain, and acts as a relay between the subcortical areas and the cerebral cortex. Finally, the hippocampus is located in the medial temporal lobe where it stores and retrieves conscious memories and processes sets of stimuli to establish the context. These findings have been discussed in detail in Nanda, Zhu, and Jansen (2011). Interestingly (and surprisingly), emotional response was also identified in response to image properties that were not content based (see Bar and Neta 2007 in Table 1). In the remainder of this article we will discuss the properties of spatial frequency and contour, identified in this article, which link to formal attributes, and have a broader applicability for the design field.

Spatial frequency

Spatial frequency is defined as the frequency of change in pixel values across an image as a function of distance (Bone, Bachor, and Sandeman 1986). It is shown that the visual system is selectively sensitive to changes in spatial frequency and hence uses different neural pathways when processing certain stimuli. Higher spatial frequencies (HSF) are processed primarily in the ventral cortical visual stream via the parvoceular channels, which have fine resolution but slow responses. On the other hand, lower spatial frequencies (LSF) are received by the dorsal parietal stream and connected subcortical regions, such as superior collculus and pulvinar areas (Vuilleumier et al. 2003). The appearance of a stimulus can convey different information with different spatial frequencies. High spatial frequencies represent abrupt spatial changes in the image (such as edges), thus corresponding to configural information and fine details, whereas low spatial frequencies represent global information about the shape (such as general orientation and proportions) (Bone, Bachor, and Sandeman 1986). See Figure 2 for an example of spatial frequency. The swift extraction of contextual meaning from an image is mediated by global cues conveyed by low spatial frequencies of an image (Bar 2004). Amygdala responses to fearful expressions were greater for LSF than HSF images (Vuilleumier et al. 2003). This implies that global information about an image is rapidly extracted (as discussed in the previous section), and induces a rapid response in the limbic system. The finding that context is rapidly extracted by low spatial frequencies of an image ties back to the quick evaluative system discussed in the previous section, and the argument that global properties of the image can shape the perception of a viewer, and trigger a primal fight or flight response, which, in turn, shapes the emotional response. In psychophysiological studies the stress response (increased heart rate, blood pressure, and cortisol) has been linked to this primal response of fight or flight, and decrease in the stress response has been linked to restoration (Ulrich 1993). As discussed before, theoretical frameworks to support this include the evolutionary theory (or biophilia theory) which states that due to years of evolution humans are hardwired to prefer and respond positively to nature images that foster wellbeing and survival (Ulrich 2009). In addition, the theory of preferenda by Zajonc (1980) states that affect precedes cognition and to that end, there are factors or ‘preferenda’ that combine with affect to cause us to evaluate and experience attraction, repulsion, pleasure, and conflict early in the sensory input. Preferendas are general and involve some kind of interaction between gross object features and internal states of the individual. Zajonc (1980) also goes on to explain that affective reactions are oftentimes separate from content (e.g. remember how a movie made one feel, but not the story behind it). Based on Zajonc’s theory of preferenda, Ulrich proposes that perception of gross structural properties of the visual envelope (i.e. those characterized by savannah-like landscapes) are thought to rapidly evoke automatic positive affective and parasympathetic physiological responses (with associated positive feelings). Ulrich postulates that certain environmental stimuli elicit primary limbic-mediated processes of affective and physiological response leading to stress restorative outcomes (Ulrich 1983). Ulrich (1983) outlines these ‘preferenda’ to include: (1) gross structural aspects of settings, (2) gross depth properties that require little inference, and (3) general classes of environmental content.

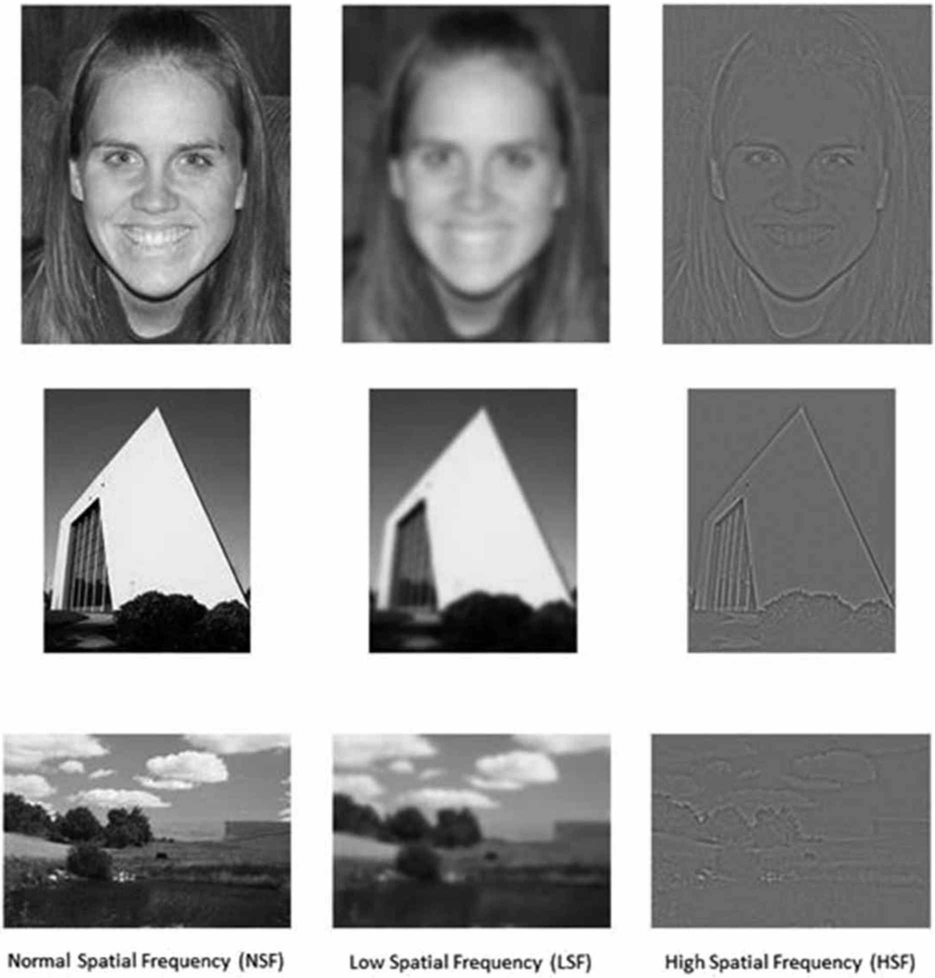

Figure 2. Examples of spatial frequency. The three images presented differed in the SF content (e.g. HSF image vs. LSF image). The original image is shown as normal spatial frequency; low spatial frequency images were filtered with a Gaussian blur at 5.0 pixels; High spatial frequency pictures were created by, blending and inverting the image, at a scale of 2 and offset of 0.

The specific finding relating to spatial frequency, and how it correlates to brain response, affords a new insight into how we design visually. It tells us that the global information about a shape, such as general orientation and proportion, can be rapidly extracted by our perceptual system, and trigger a primal response that can feed into the emotional state of fear or anxiety, even before we have completely recognized and understood it. It also takes us back to the notion of 'gist' discussed in the previous section.

Contour

The Google dictionary defines contour as an outline, esp. representing or bounding the shape or form of something. In images of three-dimensional scenes the occluding contours are theoretically defined as the lines of discontinuity of depth since they are borders between the projections of nearer and more distant objects (cf. Marr 1977; Koenderink 1984). Bar and Neta (2007) conducted a preference study on everyday objects with curved or sharp edges and found that respondents preferred objects with a curved contour compared with objects that have pointed features and a sharp-angled contour. This bias was hypothesized to stem from an implicit perception of potential threat conveyed by sharp elements. Human neuroimaging was used in the second phase of the study to test this hypothesis, and it was found that the amygdala was significantly more active for everyday sharp objects (e.g. a sofa with sharp corners) compared with their curved contour counterparts. They found that this held true for the LSF version of the images as compared with the HSF images. Authors concluded that a 'preference bias towards a visual object can be induced by low-level perceptual properties, independent of semantic meaning, via visual elements that on some level could be associated with threat . . . Our brains might be organized to extract these basic contour elements rapidly for deriving an early warning signal in the presence of potential danger' (Bar and Neta 2007, 1). The corollary to this argument is that we prefer stimuli that we do not perceive as threatening, and the key finding is that even basic perceptual elements, such as contours, can significantly shape our perceptions.

Interestingly, the Bar and Neta (2007) study explains the findings from a previous study that has been quoted often to discourage the use of abstract art in healthcare environments. In 1993, a study with heart surgery patients in the ICU of a Swedish hospital compared recovery outcomes across six groups of patients following surgery who were assigned to different picture exposures (nature and abstract images similarly dominated by greens and blues but varying in complexity levels and formal properties). Patients exposed to a representational, nature image with an open foreground and high depth of field experienced less postoperative anxiety, fewer doses of strong pain medication, but a higher intake of moderate strength pain analgesic, than patients assigned to the five other visual conditions. On the other hand, patients exposed to the abstract image with rectilinear forms showed worsened outcomes. Interestingly, another abstract image was also shown to patients – with curvilinear forms – which did not induce the worsened outcomes that the sharp rectilinear version of the image did (Ulrich, Lunden, and Eltinge 1993). Unfortunately, we do not have access to the original images used in the study, but it certainly supports Bar's thesis – even though we can argue that the pronounced effect is probably more likely in the stressed environment of an ICU, as compared with say a museum or art gallery.

Bar and Neta's work on human preference for curved contours and amygdala activation proportional to degree of angularity or sharpness of the object has drawn attention in the design community already and has been termed as 'contour bias' in the context of product design (Lidwell, Holden, and Butler 2010). Does this finding that was essentially made in the 2D context, and translated to the 3D context of objects, hold true if extended to the environmental design and architectural context?

Discussion on curved/angular forms in architecture

The discussion around contours – specifically around curves vs. sharp angles – is not a new one in design. Amir, Biederman, and Hayworth (2011) investigated the infant and adult human preferences of a singular (a straight contour) and non-singular (curves contours). The results of the study showed that both infants and adults prefer shapes with high non-singular values (curve contours) than singular values (straight contours) Also, they found that non-singular value shapes generate more activation in the lateral occipital complex, an area of the brain associated with shape recognition (James et al. 2003). The preference of curvature contours in this study was consistent with the previous studies (Ruff & Birch 1974; Cohen and Younger 1984; Quinn, Brown, and Streppa 1997; Bar and Neta 2006).

In the context of design, contour has been studied in a wide variety of backgrounds, particularly so in the sector of product design. Westerman et al. (2012) found that there was a preference for rounded designs that even extended to self-reported purchase likelihood. The experiment used images of product packaging (of a chocolate product, water, and bleach bottles) testing rounded rather than angular contours by manipulating both product shape and graphics. When looking at different contours within nature, specifically trees, Lohr and Pearson-Mims (2006) found that participants reported being happier when a slide image of spreading trees with broad canopies was shown vs. other tree forms. Jasen-Osmann and Heil (2007) conducted a study to investigate the effects of the environmental structure (circular vs. square) on spatial knowledge acquisition in a desktop virtual experiment which provided a self-determined moment for children and adult participants. The results of this study indicated that the learning of a route in a circular environment was much easier rather than in a square environment. In his doctoral work Madani Nejad (2003) found that curvilinear forms in interior residential architectural settings were perceived as less stressful compared with more angular and rectilinear forms. In addition, curvilinear forms were perceived as more private and safer. The author hypothesizes, based on a mixed-method study with architects and non-architects, that adding curvature to design can create spaces that are felt to be more pleasant, relaxing, and calming, and make them more joyful and serene.

If we overlay what we know from environmental psychology and design research studies to insights from neuroscience discussed earlier, we can now make some neuro-architecture hypotheses:

1. Formal elements of a designed visual environment can be rapidly extracted to trigger a response in the limbic system.
2. Curvature in the form can change the quality of the above response and affect subsequent emotional experience.

The underlying assumption in the above hypotheses is that the initial primal response, which is rapid, and arguably pre-cognitive, would act as a trigger for the subsequent, and more sustained, emotional response. Since the discussion looks at a formal property exclusively, we also need to assume a certain functional equivalence – allowing us to compare apples with apples – e.g. would a chaise with a curved form be perceived as more comfortable than a chaise with an angular form; or conversely, would a knife with a curved handle be perceived as less dangerous than a knife with an angular straight edged handle?

Given the complexity of emotional and cognitive processing in the human brain, we cannot suggest that curvature in the form would 'exclusively' drive any experience. The emphasis on rapid extraction and 'initial' response is to focus on the response in that first glance, first look, and first impression, while appreciating that this rapid response may well be mediated by higher-level cognitive processes and individual traits, given additional time.

Emotion follows form follows function – What this means for architecture

Formal aspects of a visual stimulus can be rapidly extracted to trigger an emotional response, measurable at the level of brain behaviour – this idea has a significant implication for design. In this article we started our investigation into this idea from the negative emotions prevalent in high stress settings such as hospitals, and investigated how visual properties that relate to the form rather than content can be rapidly extracted (through the low spatial frequency) features, including basic shape information lent by the contour. We also found that the amygdala response, which is linked to a primal fight or flight response, as well as a relay centre to higher level emotional processing, is more heightened when the contours (of functionally equivalent objects, or semantically neutral objects) are sharp-edged compared with curved. We found support for this neuroscience investigation in other studies on preference, and self-reported stress response, at the scale of interior design and product design. It is important to note that in our review of the literature there were no studies cited which investigated the effect of images of architectural spaces (interior), or building envelops (exterior) at the neuro-level.

It is important to note here that the amygdala response is an emotional primer, which is not absent in positive emotions. In fact, studies show that the amygdala is as important for processing positive reward and reinforcement as it is for negative (Murray 2007). Although the thrust in the literature today is on the amygdala as a protective mechanism, linked to primal responses that keep us from harm, as well as a relay centre linked to the processing of negative emotions, there is also a significant body of research that states the role of the amygdala is to establish emotional salience, and that positive and negative valenced stimuli are both processed by the amygdala, albeit by different regions. In this article, we have focused on form, devoid of content. Thus, the issue of valence (positive or negative) has been less relevant. However, as insights on form are layered with issues of function, and context, this reminder is important. It also begs the question if amygdala response, triggered by formal attributes such as curved or sharp contours, can, based on the context, result in a heightened negative OR positive response.

Intrinsic to the design process are decisions on forms, shapes, and contours, in response to a building programme. Through walls, floors, and roofs, designers essentially create forms that are experienced both from the exteriors and the interiors. Also, built form is experienced both as convex surfaces and concave surfaces simultaneously (from exteriors and interiors), depending on the formal vocabulary adopted for a project. If viewers respond to formal attributes of single-plane visual stimuli (as in artwork and imagery) the same should hold true for stimulus incident from the ambient three-dimensional environment. This is particularly so in the context of stressful environments where the negative response may be more acute.

If we look at architectural practice there are many instances where designers implicitly employ formal tools to elicit immediate emotional responses, across setting types. Healthcare and justice architecture constitute exemplary cases where such emotional responses have been targeted in recent decades. In healthcare, substantial emphasis has been accorded to not only the overall shape of the building, but more specifically to the form and shape of the main public lobby, both from the outside and the inside. Since the advent of the evidence-based design model, designers have attributed healthcare facility (mostly acute care) forms to such concepts as hope, place attachment, warmth, homelike, etc. (Blouin 2006; Herman 2009; Peck, 2009; Vickery, 2010; Pati 2011; Nigrelli 2012; Vickery, 2012). The unstated and unarticulated hypotheses seem to be that the evocation of such emotions would result in pacification of anxiety and stress, and hence better treatment and recovery. In a different context, and for a separate objective, federal justice design has witnessed a similar revolution since the 1990s (Pati, Zimring, and Bose 2007). With a general perception among elected representatives regarding a widening gap between the State and the citizens, justice facilities were targeted to repair and change public perception. Starting off with a programme named 'First Impression' that targeted the main entrance and the lobby, the US Federal Government embarked upon one of the largest expansions of federal courthouses since the Work Projects Administration (WPA) era. Once again, the primary emphasis was on visual stimulus and the associated emotional response. The objectives were more explicit – to evoke appropriate emotional response so as to change the perception regarding the State (the government). Newer federal courthouses rapidly discarded the traditional Greek Temple language and explored formal vocabulary in an intensity that has resulted in a portfolio of courthouses representing a wide array of forms and shapes. The intent was to instil a sense of belongingness. It is evident that emotional affordance is important to designers (and users), as is functional affordance.

While functional affordance is easy to test, emotional affordance can be much more difficult. To begin to tackle this question, before we address the complex, we must tackle the simple – taking one visual property at a time, so we can then address how different properties come together, to define different experiences. Being able to test one visual property at a time, against a neural response, allows us the ability to create evidence-based building blocks for design practice. Granted that form is not the only factor; in fact, in a utilitarian field such as architecture, form is a slave to function. Even so, it is obvious in the choice of forms that functionally equivalent objects, spaces and buildings, boast that something beyond function drives the process of design. Also, in a world where information is rapidly displayed, and rapidly consumed, and where choices are often split second, even among functionally equivalent objects (say choice of a cell phone), or places (choice of a hotel destination), understanding the immediate emotional response is of great value. The other extreme is the importance of rapid affective response in environments where there is minimal choice – and perhaps maximum stress – such as healthcare environments. Here, the relevance goes beyond preference, to the issue of emotional triggers, which may induce a negative emotion in a far more potent fashion, than other places where a person is not as vulnerable. In other words, if indeed sharp-edged objects/spaces induce a heightened response in the amygdala than their curved counterparts (assuming that functionally and semantically the two are the same), then in a hospital where a person is more stressed, and therefore more primed for a negative response, the response would be far stronger, than say in a mall or a museum. In fact, the amygdala response which in a hospital setting, especially in highly vulnerable situations such as post-surgery, could lead to heightened fear and anxiety. However, the same environment, and arguably the same pre-cognitive response, could lead to emotions of heightened excitement and intrigue in say a theme park or a risqué art show.

If we look at iconic architectural buildings, they consist of a juxtaposition of straight and curved forms, they boast of high soaring steeples on the one end, and broad sprawling earth-hugging forms on the other. Certainly, there are more examples of straight edges in architecture, than more amorphous, gentle curves. And yet, if we look at nature it seems we observe the exact opposite. It is hard to find straight lines that so dictate our man-made environments, in any natural form. The primal response to curved form, that this article has discussed, and its potential in being an emotional trigger, is an insight that could not have been possible without reviewing neuro-architecture. In behavioural studies the initial primal response may well be over-ridden by behavioural manifestations of higher level cognitive responses. But understanding the initial primal response is an opportunity for designers to hone that initial spark to create spectacular emotional affordances in any design object, space, or building.

Unfortunately, at this time all the neuro-evidences that we have garnered have been from images of natural scenes, faces, abstract forms, and basic objects. Having honed in on a very specific attribute – manipulation of curvature in form – the time is right to test if the insights from the literature hold true with images of three-dimensional spaces (interior and exterior).

At the time of composing this article the authors are designing a study at Texas Tech University's Neuro Imaging Institute to examine that exact question – are three-dimensional forms varying primarily in their formal property of curvature/angularity systematically and predictably associated with specific emotional responses. It intends to expand the current body of work to the architectural and interior design context. Figure 3 shows some of the basic visuals that will be used for the study. Interiors, exteriors, and landscape scenes will be added using simulations as well as real life examples. The findings of the study (expected to conclude in 2013) are expected to provide a potent and objective route to engineering emotions through form, and a way to harness neuroscience theories, tools, and methods to deliver predictable functional outcomes in the built environment.

Billions of dollars are spent in the creation of building forms and envelopes, arguably to elicit desired emotions, over and beyond just utilitarian functions. If this had not been the case, then the building, and indeed the interiors, may have looked very different. The lack of articulation of the

Figure 3. Form and the built environment.

specific emotion to be elicited (or avoided), and the lack of metrics to measure emotion as well as the design features, has caused such discussions to be more rhetoric than science. Neuro-architecture creates an opportunity to change this – to use science to drive innovation in a most fundamental way – even as we take small baby steps towards it – exploring one critical dimension at a time.

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