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Effects of expertise on psychological responses to buildings and natural landscapes

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ABSTRACT

Recent work on the aesthetics of the built and natural environment has shown that aesthetic responses are derived from three interrelated psychological dimensions: Fascination (an environment's richness or interest), Coherence (analytic judgments about an environment's organization and construction), and Hominess (feelings of warmth or coziness). However, it is also well-established that individuals differ widely in their responses to environments and objects. In particular, training in the arts has been reliably shown to influence people's aesthetic experiences. Here, we investigated the extent to which expertise in architecture and design influenced responses and preferences to the natural and built environment. Across three studies, we found that the underlying psychological dimensions of Experts and Novices are qualitatively different. We further hypothesized that expertise in architecture renders design features of the environment to be more emotionally and aesthetically pleasing. Consistent with this hypothesis, the Coherence dimension of architecture Experts was more strongly associated with Fascination and Hominess criteria, and had a greater influence on their overall aesthetic experience. Additionally, our findings provide evidence of expertise effects for both rapid and deliberate judgements. In sum, the present study extends a growing body of research on the underlying psychological dimensions of aesthetic experiences of the environment, demonstrating that expertise affects the interrelatedness of these dimensions.

1. Introduction

The aesthetics of the built and natural environment impact mood (Abboushi, Elzeyadi, Taylor, & Sereno, 2019; Beute & de Kort, 2018; Coburn, Vartanian, & Chatterjee, 2017; MacKerron & Mourato, 2013; Meidenbauer et al., 2020; Ulrich, 1991), cognition (Berman, Jonides, & Kaplan, 2008; Bratman et al., 2019; Earthman, 2004; Mehta & Zhu, 2009; Schertz et al., 2018), productivity (Bossaller, Oprean, Urban, & Riedel, 2020; Shen, Zhang, & Lian, 2020; Wu et al., 2021), and health (Berman, Kardan, Kotabe, Nusbaum, & London, 2019; Bratman et al., 2019; Gillis & Gatersleben, 2015; Kellert, 2012; Roe & Aspinall, 2011). One of the promises of empirical aesthetics is to use experimental findings to inform real-world design to foster benefits across these areas. As such, a major objective of this research has been to determine how and why people respond to different objects and environments across a broad range of contexts, and to establish general principles underpinning aesthetic preferences and responses. Complementary work identifies sources of individual variability in these responses. That is, how and why do people vary in their responses to objects and the environment?

The question of individual differences is valuable for several reasons. First, it is imperative that research identify sources of variability in responses across individuals and groups so that architects and designers can construct environments to match the preferences of would-be inhabitants. People with autism spectrum disorder (ASD), for instance, have different preferences for the built environment than individuals with neurotypical development (Belin, Henry, Destays, Hausberger, & Grandgeorge, 2017; Vartanian, Navarrete, Palumbo, & Chatterjee, 2021). Thus, if one designs a space for ASD, population-specific preferences become relevant. Second, comparing different groups of people can broaden understanding of how prior experiences, motivations, personality traits, or cultures moderate aesthetic responses. For

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example, the finding that art history students prefer asymmetry (whereas other students prefer symmetrical visual stimuli; Corradi, Chuquichambi, Barrada, Clemente, & Nadal, 2020; Leder et al., 2019; Weichselbaum, Leder, & Ansorge, 2018) demonstrates how education influences the ways in which people engage with objects, shedding light on the nature of aesthetic experience and expertise more broadly. The present study tests the hypothesis that expertise in architecture and design influences responses and preferences to the natural and built environment.

1.1. Aesthetics of the built and natural environment

Recent work indicates that psychological responses to the built and natural environment are explained by three interrelated underlying psychological dimensions: Fascination (the extent to which an environment is visually rich and interesting), Coherence (analytic judgements about an environment's organization and legibility), and Hominess (feelings of warmth or coziness; Chatterjee, Coburn, & Weinberger, 2021; Coburn et al., 2020; Vartanian et al., 2021; Weinberger, Christensen, Coburn, & Chatterjee, 2021). Each dimension is strongly related to valence felt (i.e., positive or negative feelings evoked by a space makes a viewer feel) and corresponds to different neural patterns of activation (Coburn et al., 2020). Fascination, Coherence, and Hominess have been identified across different kinds of natural and built environments (Weinberger et al., 2021).

According to the aesthetic triad model (Chatterjee, 2014; Chatterjee & Vartanian, 2014, 2016), aesthetic preferences and responses emerge from three large-scale interrelated neurocognitive systems: sensory-motor (sensation, perception, and motor system), emotion-valuation (reward, emotions, wanting/linking), and knowledge-meaning (expertise, context, and culture). When applied to the built and natural environment (Coburn et al., 2017), the sensory-motor system is engaged when processing visual, acoustic, tactile, and olfactory features. Responses from the emotion-valuation system may range from feelings of joy or delight to fear and disgust. The knowledge-meaning system mediates sensory and emotional responses based on cultural background, identity, and education, pointing to a plausible source of variability in aesthetic responses across individuals. For example, the aforementioned preferences of art history students for asymmetry (Corradi et al., 2020; Leder et al., 2019; Wiesmann & Ishai, 2011) likely result from variability in the knowledge-meaning system. Specifically, learning about art history can affect one's understanding of a piece of art, thereby altering the "backdrop" against which an individual evaluates a visual object. Similarly, formal training in architecture and design changes people's preferences for curvilinear and rectangular architectural design (Vartanian et al., 2019).

Other compatible models of aesthetic experience make a distinction between analytic judgements (i.e., evaluations about the stimulus itself) and emotional responses (i.e., how the stimulus makes one feel; Chatterjee, 2003; Leder, Belke, Oeberst, & Augustin, 2004). As it relates to the environment, the Coherence dimension of aesthetic experience is primarily driven by analytic judgements – e.g., How organized or complex is a space? Does it look modern? Prior work indicates that Coherence is *somewhat* separable from people's affective responses, which are more strongly reflected in Fascination and Hominess (Coburn et al., 2020; Weinberger et al., 2021). This is not to say, however, that Coherence is fully distinct from affective responses. Indeed, Coherence is still weakly linked with Fascination and Hominess, albeit less strongly than Fascination and Hominess are associated with each other (Weinberger et al., 2021). In the present study, we specifically tested the hypothesis that formal training in architecture and design differentially influences the relationship between Coherence (primarily analytic evaluations) and Fascination and Hominess, which are comprised of more emotional criteria.

1.2. Individual differences in aesthetic experience

Individual variability in aesthetic experience is well-documented, and can originate from wide-ranging person-to-person differences. According to the mere exposure effect, people prefer stimuli they have viewed repeatedly (Bornstein & D'agostino, 1992; Montoya, Horton, Vevea, Citkowicz, & Lauber, 2017), suggesting an individual's familiarity with a given object mediates their responses. It is worth noting, however, that the fluency effect is not uniform across stimuli and exposure durations (Montoya et al., 2017). Aesthetic experience is also influenced by context and knowledge; people like art more if presented with information about the piece's cultural value (Kirk, Skov, Christensen, & Nygaard, 2009; Leder et al., 2004). Other work – across several artistic domains – has demonstrated variability in how people respond to art and objects across cultures (Che, Sun, Gallardo, & Nadal, 2018; Darda & Cross, 2021; Monroy, Imada, Sagiv, & Orgs, 2021). The role of individual differences is well-described by a recent account of "aesthetic sensitivity" that argues that the extent to which specific features influence an observer's liking or preference determine the nature of an aesthetic experience (Corradi et al., 2020), with such sensitivity influenced by the history of a person's culture, learning experiences, and exposure.

1.2.1. Effects of expertise

Another source of individual differences in aesthetic responses – and one that has been the subject of substantial experimental inquiry – is expertise. Training in the arts reliably impacts people's aesthetic responses (Azemati et al., 2020; Chamberlain, 2018; Chamberlain et al., 2019; Chamberlain & Wagemans, 2015; Fayn, Silvia, Erbas, Tiliopoulos, & Kuppens, 2018; Gartus, Völker, & Leder, 2020; Gifford, Hine, Muller-Clemm, Reynolds, & Shaw, 2000; Jam, Azemati, Ghanbaran, Esmaily, & Ebrahimpour, 2021; Kirk et al., 2009; Silvia, 2005, 2006; Silvia & Barona, 2009; Vartanian et al., 2019, 2021; Walker, 1980). In the visual domain, these differences may be particularly strong for sensitivity to specific visual features. For example, art expertise is linked to greater preference for abstract paintings because training allows individuals to appreciate mastery or "visual rightness" (Bimler, Snellock, & Paramei, 2019; Pihko et al., 2011). That is, experts are better able to connect the appearance of a final product with the skills of the painter who created it. Moreover, people with greater knowledge of a work of art show deeper engagement with the material, leading to more fine-grained emotional experiences (Fayn et al., 2018), consistent with the influence on the knowledge-meaning system on aesthetic appreciation. Other research has demonstrated a link between expertise and preference for complexity (Leder et al., 2004; Tamás, Barta, & Szamosközi, 2021) and asymmetry (Azemati et al., 2020; Gartus et al., 2020). Training in mathematics alters aesthetic judgements of math equations, presumably because expertise altered how an equation is experienced (Hayn-Leichsenring, Vartanian, & Chatterjee, 2021). By contrast, more "basic" affect such as valence or arousal may be less influenced by formal training (Paasschen, Bacci, & Melcher, 2015). The extent to which expertise effects are separable from the aforementioned influences of exposure is an open question.

A growing number of studies have investigated the effects on expertise on aesthetic responses to the environment. When forming emotional assessments of the built environment, architects consider a different set of building features than do laypeople (Gifford et al., 2000; see Šafárová, Pírko, Juřík, Pavlica, & Németh, 2019 for an alternative account). Eye tracking studies further show that, when viewing images of building facades, architects not only show different preferences but they also look at different locations and for different durations (Jam, Azemati, Ghanbaran, Esmaily, & Ebrahimpour, 2021). Experts also show different preferences for curvature in architecture and design (Vartanian et al., 2019). Most notably, researchers explored whether design expertise mediated the degree to which preferences to images of building interiors were influenced by Coherence, Fascination, and

Hominess (Vartanian et al., 2021). Participants were presented with a series of images of building interiors and had 1500 ms to indicate whether or not they liked each room. Researchers tested whether Coherence, Fascination, and Hominess exhibited different influence on liking judgements for expert and novice participants. They predicted that formal training in architecture would render Coherence – which captures analytic evaluations about a scene's appearance – particularly salient for experts. Findings were consistent with this prediction; expert preference judgements were associated with the Coherence dimensions whereas novice preferences were influenced by Fascination and Hominess.

Several theories explain these observed results. Martindale and colleague's (1990) "prototypical" theory of aesthetic emotions argues that responses to art are related to the extent to which a given object fits a "prototype". Experts respond differently to art because formal training changes their catalog of prototypes. The processing fluency theory – which states that beautiful objects are more easily/efficiently processed (Reber, Schwarz, & Winkielman, 2004) – suggests that individuals process objects within their domain of expertise more fluently, and thereby find such objects to be more aesthetically pleasing. Processing fluency is supported by experimental work using fMRI that found that architecture students recruited fewer brain regions upon repeated presentations of buildings (Wiesmann & Ishai, 2011), suggesting greater neural efficiency. Specific design features that can only be appropriately discerned by experts might in turn elicit different psychological responses (Kölbel, 2016). Another account states that aesthetic evaluations are closely related to an individual's thoughts and beliefs about an observed object (Ellsworth & Scherer, 2003; Lazarus, 1991; Silvia, 2005, 2006). In the case of expertise, different aesthetic responses are because of differences in how people think about the art, environment, or object (i.e., appraisals). Different appraisals, in turn, generate different levels of interest among experts and novices. Consistent with appraisal theories, individuals with art training find complex pictures easier to understand and, consequently, more interesting (Silvia, 2006). This effect has also been observed for film and television; experts find complexity interesting (i.e., a complexity × expertise interaction; Silvia & Berg, 2011).

In the present study, we tested whether expertise mediates the extent to which the design features of the built environment (reflect most strongly in the Coherence dimension) are associated with emotional responses images of buildings. Extending the above-discussed findings that experts show greater appreciation of mastery and visual form in paintings (Bimler et al., 2019; Pihko et al., 2011), and experience more nuanced aesthetic emotions (Fayn et al., 2018), we predicted that the association between Coherence and Hominess and Fascination would be stronger for architecture experts. That is, expertise in architecture enables individuals to identify a buildings' visual rightness or architectural mastery, leading to a stronger link between a buildings' design features (i.e., Coherence) and their responses to it (Fascination, Hominess).

One outstanding question is whether the impact of expertise can be observed across judgments of varying durations. That is, do experts' rapid, initial evaluations differ from those of novices. Alternatively, do expert participants react similarly at first, but develop different responses and preferences only after a period of consideration? Experimental inquiries into this question yield mixed results. In favor of somewhat delayed expertise effects, art students show better control of attention processing during drawing measures and some visuospatial tasks, but are not different on low-level visual processing (Chamberlain et al., 2019). This observation is consistent with a top-down role of the knowledge-meaning system of the aesthetic triad (Chatterjee, 2014; Chatterjee & Vartanian, 2014) as well as other theoretical accounts indicating that the effects of culture operate via top-down mechanisms (Redies, 2015). Other work, however, indicates changes to more immediate or rapid processing. Mehaffy and Salingaros (2006) used an implicit association test to show that experts can be distinguished by both implicit and explicit preferences when evaluating objects, showing a preference for modern – rather than classic – designs. Vartanian et al. (2021) observed expertise effects on 1500 ms judgements, also suggesting fairly quick differences in responses because of expertise. These results are also supported by substantial body of work from learning and memory literatures more broadly, which have linked expertise with greater automaticity when performing a trained task (e.g., Gobet & Charness, 2018; Norman et al., 2018; Posner & Rothbart, 2014; Ullman, 2004). Another outstanding question – and one that has received little investigation – is whether expertise effects stem from domain-specific knowledge (e.g., how to assess the structural quality of a building) or more domain-general skills (e.g., analytic evaluations).

1.3. Present study

Here, we applied techniques from network science and mixed effects models to broaden our understanding of how expertise in architecture and design influences responses to the built and natural environment. Across three studies, we first tested the hypothesis that aesthetic responses to images of the built and natural environment reduce to a few broad yet interconnected underlying psychological dimensions (H1). This hypothesis builds off recent work demonstrating that responses are derived primarily from dimensions of Coherence, Fascination, and Hominess. However, we also hypothesized that aesthetic responses to the environment are influenced by architectural expertise (H2). That is, we anticipated that the underlying psychological dimensions of experts would differ qualitatively from the underlying responses of laypeople. We further hypothesized that expertise in architecture renders design features of the built environment (reflected in Coherence) to be more emotionally/aesthetically pleasing (H3). Thus, while both experts and non-experts can assess design features, we predicted that the Coherence dimension would be weakly associated with Fascination and Hominess criteria for novices (consistent with past work; Weinberger et al., 2021). By contrast, experts' analytic observations about a space's appearance (Coherence) may be more sensitive to mastery and bring about a deeper or more nuanced emotional response (i.e., more reflected in Fascination and Hominess), suggesting a greater influence of Coherence on their overall aesthetic experience.

To investigate the question of cognitive mechanism, we also tested (in Study 3) competing hypotheses about whether expertise effects are evident for rapid judgements or more deliberate ones. One possibility (H4A) is that training in architecture/design changes one's initial impressions when making an aesthetic judgment. In the case of the present study, we would therefore predict that experts and novices exhibit different preferences when asked to provide fairly rapid judgements. Alternatively, expertise may exert a top-down influence (H4B) that occurs later in time as an aesthetic response evolves. Thus, we would predict that differences between experts and novices is apparent for deliberate judgements.

2. Analytic approach

For each of the three studies described in the present manuscript, participants rated images of different environments on a several theoretically important aesthetic criteria (see Coburn et al., 2020, Table 1). We applied a network-based form of dimension reduction to examine participants' underlying psychological responses to these images. That is, we sought to identify emergent mental states related to associations between the different criteria. Specifically, we used exploratory graph analysis (EGA; Golino et al., 2020; Golino & Epskamp, 2017) to estimate participants' underlying psychological responses to images of buildings and natural landscapes. EGA is a recently developed method to estimate the number of dimensions in multivariate data, and has been shown to outperform alternative methods of dimension reduction (e.g., PCA) when observation variables are highly correlated (Golino & Epskamp, 2017; Golino et al., 2020). EGA first applies a network estimation method (here, graphical least absolute shrinkage and selection operator;

Table 1
Aesthetic rating criteria.

Criteria	Rating Prompt	Low Anchor	High Anchor	Dimension
Complexity*	This space looks …	Simple	Complex	Coherence
Order*	This space looks …	Disordered	Organized	Coherence
Natural*	This space looks …	Artificial	Natural	Hominess
Beauty*	This space looks …	Ugly	Beautiful	Fascination
Personalness*	This space looks …	Impersonal	Personal	Hominess
Interest*	This space looks …	Boring	Interesting	Fascination
Modernity	This space looks …	Aged	Modern	Coherence
Valence*	This space makes me feel …	Bad	Good	Fascination
Stimulation	This space makes me feel …	Bored	Excited	Fascination
Vitality	This space makes me feel …	Lifeless	Alive	Fascination
Comfort	This space makes me feel …	Uncomfortable	Comfortable	Hominess
Relaxation	This space makes me feel …	Stressed	Relaxed	Hominess
Hominess*	This space makes me feel …	Alienated	At home	Hominess
Uplift	This space makes me feel …	Diminished	Uplifted	Fascination
Approachability*	If I saw this space, I'd …	Leave it	Enter it	Fascination
Explorability	If I saw this space, I'd …	Ignore it	Explore it	Fascination

Note: Asterisk indicates inclusion in Study 1.

Friedman, Haste, & Tibshirani, 2008, 2014), with aesthetic criteria (see Table 1) modeled as "nodes" and connections ("edges") between nodes based on partial correlations between the criteria. A Louvain community detection algorithm (also referred to as Multi-level; Newman, 2006; Blondel, Guillaume, Lambiotte, & Lefebvre, 2008; Gates, Henry, Steinley, & Fair, 2016) for weighted networks (Fortunato, 2010) was then used to place aesthetic criteria into "communities". Nodes that fall within the same community behave similarly to each other (i.e., they are strongly associated), suggesting that they relate to a shared underlying construct. For example, past work has found that Complexity, Modernity, and Organization (see Table 1; Weinberger et al., 2021) are more strongly associated with each other than they are with other aesthetic criteria, leading to the placement of these three criteria into their own community (Coherence). This approach is conceptually equivalent to components derived from techniques such as PCA. Separate EGAs were performed for Expert and Novice participants to allow for a side-by-side qualitative comparison of network organization for the two groups. From a practical perspective, another advantage of EGA is the ability to visualize or map associations between observation variables. That is, one easily identify the strength of connectivity between nodes of a network. See Supplementary Information for more on EGA implementation.

In addition to questions about community placement, we also predicted that one of the major differences between Experts and Novices would be the extent to which the three main psychological responses identified in past work – i.e., Coherence, Fascination, and Hominess – influence overall aesthetic experience. To be clear, this question is *not* about how different aesthetic criteria form separable communities/dimensions, but instead concerns how strongly connected each criteria is to every other criteria (i.e., its relevance), *independent of community affiliation*. This prediction was tested by calculating eigenvector centrality (EC) of each node in the EGA-derived networks for Expert and Novice participants. EC, a metric from network science, measures the relative position of nodes in a network by examining their connections to highly-connected nodes relative to weakly-connected nodes. Nodes with higher EC have a greater connectivity to highly connected nodes in the network. Thus, separate from questions about community organization (i.e., based on EGA), EC indicates the extent to which an individual node is relevant to the overall measurement of the constructs in the network. For example, if EC for the "Complexity" node in the Expert participant network is greater than in the Novice network, one could conclude that this specific aesthetic criterion is more relevant to the overall aesthetic experience of Expert participants. EC is like the gravitational pull of an individual node on the other nodes in the network. After calculating EC for each network node in the Expert and Novice networks, permutation testing was performed to identify significant differences in EC between the groups.

3. Study 1

3.1. Method and materials

Six hundred and fourteen participants completed the study online via Amazon Mechanical Turk. Detailed study procedures for this sample have been described elsewhere (Coburn et al., 2020). Briefly, participants rated 16 different images of building interiors on 9 aesthetic criteria (Table 1) using a 7-point Likert scale (1 = low, 7 = high), resulting in 144 total ratings per participant. Architecture expertise was assessed at the conclusion of the study with a single item: "How much experience or education have you had related to architecture?“. Participants responded using a sliding Likert scale (−3 = very little, 3 = a lot).

Responses to the architecture expertise item indicated strong floor effects (i.e., most participants reported little expertise; $M_{\text{expertise}} = -1.21$, SD = 1.63). To explore the effects of expertise on aesthetic experience, we created two subgroups from this item. Participants who indicated a value of −3 (corresponding to the bottom 25.5% of the full sample) were classified as the "Novice" group (N = 157; M_{age} = 37.26 years, SD = 10.78 years; 60.0% female, 38.2% male) and those who reported a value larger than 0 (upper 23.5% of sample) were classified as the "Expert" group (N = 145; M_{age} = 35.47 years, SD = 11.63 years; 38.9% female, 52.9% male). All other participants were dropped from the analysis.

3.2. Results

3.2.1. Underlying psychological responses

We first asked whether expertise influenced the underlying psychological responses using EGA. Results identified three communities for the Novice group (Community 1: Coherence, $\lambda = 1.51$; Community 2: Hominess, $\lambda = 2.03$; Community 3: Fascination, $\lambda = 2.87$) and two communities for the Expert group (Community 1: Combination of Fascination and Coherence, $\lambda = 3.76$; Community 2: Hominess, $\lambda = 1.96$; Fig. 1). These results suggest that Hominess – which was preserved in the two participants groups – is a component of aesthetic experience that is reasonably stable across differing levels of expertise. By contrast, Coherence and Fascination collapsed into a single community for Experts, consistent with the interpretation that more analytic evaluations (i.e., Coherence) become integrated with more emotional responses (Fascination) with greater expertise.

3.2.2. Relevance of underlying dimensions on overall aesthetic experience

To investigate criteria relevance on the underlying aesthetic

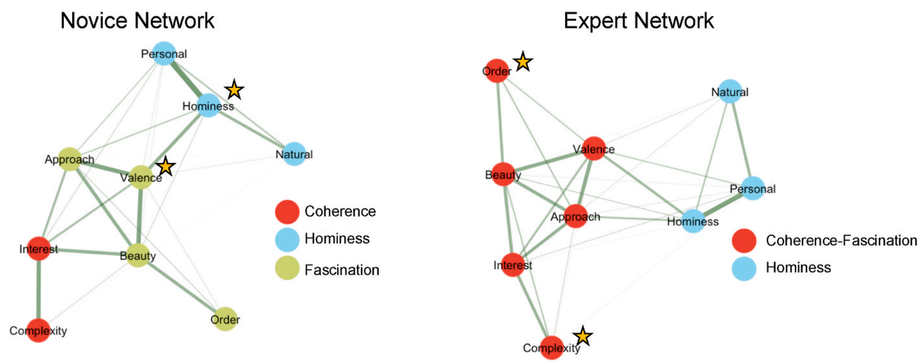

Fig. 1. Study 1 EGA results. Graphs formed from partial correlations between aesthetic rating criteria. Connectivity strength represented by edge thickness (thicker = stronger association). Nodes that are significantly higher in eigenvector centrality (EC) for one network than another are indicated by a star. For example, Hominess EC is significantly greater in the Novice network than in the Expert network.

responses of experts and novices (i.e., how strongly is each node connected to every other node), we next computed eigenvector centrality (EC) of each node in the Expert and Novice networks using the *NetworkToolbox* package (version 1.4.4; Christensen, 2018) in R (version 4.0.3; R Core Team, 2022), and conducted permutation tests to quantify group differences. Nodes with higher EC have a greater relevance to the network as a whole (i.e. overall aesthetic experience), regardless of their community affiliation. As expected, results indicated significantly greater EC in the Expert network for the two analytic Coherence criteria – Complexity ($p = 0.004$) and Order ($p = 0.012$) – demonstrating that the Complexity and Order had greater relevance on the overall aesthetic experience of Experts. By contrast, the network of the Novice group was characterized by a greater EC of two emotional criteria: Valence ($p = 0.03$) and Hominess ($p = 0.02$; Fig. 1; SI), suggesting that Valence and Hominess are more relevant for Novices' aesthetic experience.

3.3. Discussion

The underlying psychological responses of the Novice group was characterized by three dimensions: Coherence, Fascination, and Hominess. Among Experts, however, EGA revealed only two communities: (1) Hominess, and (2) a combined Coherence-Fascination dimension. This suggests that the criteria that come together to create feelings of Hominess – Personal, Natural, and, of course, the Hominess criteria – are shared across a ranges of expertise. By contrast, the criteria that comprise Coherence and Fascination are modified by expertise. Group differences in EC further demonstrated that Coherence may have a greater influence on the overall aesthetic experience of architecture experts than novices, in line with our prediction. On the other hand, Valence and Hominess are more relevant (i.e., they have greater EC) to novices. Finally, Expert and Novice groups were characterized by differences in gender (i.e., there were more women in the Novice group and more men in the Expert group). We made no hypotheses concerning gender as a mediating factor on expertise. Future work on expertise effects may benefit from a more thorough investigation into this particular limitation.

4. Study 2

In Study 2, we extended findings from Study 1 by including images of building exteriors *and* natural landscapes – affording the opportunity to investigate the specificity of expertise effects. That is, are differences in aesthetic experience limited to the specific area of expertise (i.e., architecture images) or do they generalize to a similar but different domain (i.e., natural environment images)? Study 2 images were also more varied, and not curated like those used in Study 1 (see Weinberger et al., 2021).

4.1. Method and materials

Two hundred and fifty three participants completed the study on Amazon Mechanical Turk (detailed procedures previously described in Weinberger et al., 2021). Study 2 stimuli included 64 images of building exteriors and 64 images of natural landscapes. Each participant was randomly presented with 8 images of buildings and 8 images of landscapes, and rated each image on the aesthetic criteria (Table 1) using a 7-point sliding Likert scale. "Naturalness" was excluded for images of natural landscapes, as applying this criteria to natural spaces is not sensible (Weinberger et al., 2021). The study concluded with a single-item measure to self-report architecture expertise (i.e., Likert scale with values from −3 to 3).

Participants who fell in the bottom 25th percentile of the architecture expertise item were classified as the Novice group (Expertise item < -2.8; N = 63; M_{age} = 40.71 years, SD = 10.87 years; 55.56% male, 42.86% female) and those who scored in the top quartile were classified as the Expert group (Expertise item >1.3; N = 64; M_{age} = 36.39 years, SD = 9.08 years; 67.19% male, 32.81% female).

4.2. Results

Separate EGAs were performed for images of buildings and landscapes – and for Expert and Novice groups – to identify underlying psychological responses.

4.2.1. Building exteriors

Underlying psychological responses. EGA results for the Novice group were broadly consistent with the three-dimensional structure of Coherence, Fascination, and Hominess (Fig. 2). Community 1 ($\lambda = 1.53$) contained the analytic criteria associated with Coherence (along with Naturalness) and was isolated from the rest of the network, indicating that, for novices, analytic judgements were detached from the more emotional aspects of aesthetic experience. Community 2 ($\lambda = 4.27$) contained Hominess criteria as well as two broadly applied criteria of aesthetic experience – Beauty and Valence. The remaining aesthetic criteria were placed in the Fascination dimension (Stimulation, Interest, Approach, Explorability; $\lambda = 3.09$) and a two-item dimension (Uplift and Vitality; $\lambda = 1.64$) that underscores an energized emotional state that is typically associated with Fascination. By contrast, all 16 aesthetic criteria fell into a single dimension for the Expert group ($\lambda = 6.58$), demonstrating a strong link between emotional and analytic criteria. The presence of a single community further indicates that Experts may apply the aesthetic ratings in a holistic manner.

Influence of underlying dimensions on overall aesthetic experience of buildings. To quantify these observations, we again compared EC of the Expert and Novice network nodes. Replicating findings from Study 1, the Expert network was characterized by significantly greater

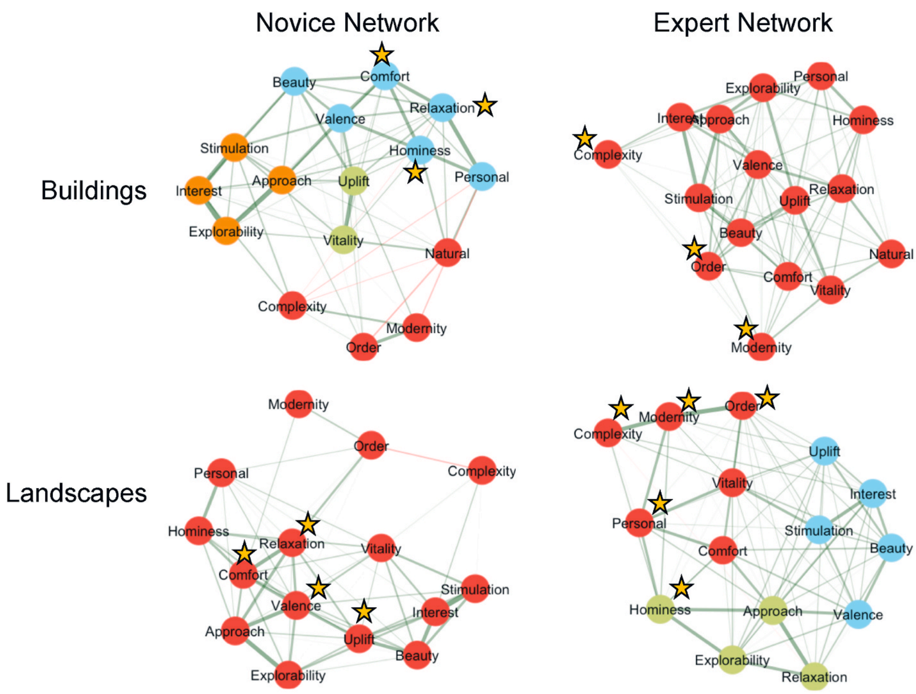

Fig. 2. Study 2 EGA Results. Graph formed from partial correlations between aesthetic rating criteria. Connectivity strength represented by edge thickness (thicker = stronger association). Red edges indicate a negative association between the criteria. Nodes that are significantly higher in eigenvector centrality (EC) for one network than another are indicated by a star. For example, Comfort EC for Buildings is significantly greater in the Novice network than in the Expert network. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

influence of nodes associated with the analytic Coherence dimension; EC was greater for Complexity ($p = 0.003$), Order ($p < 0.001$), and Modernity ($p < 0.001$; Fig. 2; SI). Also closely mirroring Study 1 results, the Novice network exhibited greater EC of Hominess nodes (Comfort: $p < 0.001$; Relaxation: $p = 0.006$; Hominess: $p < 0.001$; SI). In sum, these findings indicate that analytic judgements about a building's construction (i.e., as broadly captured by Coherence) had a stronger influence on the aesthetic responses of Experts whereas Novice participants were more strongly influenced by Hominess.

4.2.2. Natural landscapes

Underlying psychological responses. EGA results for natural landscapes were largely the opposite of those observed for building exteriors (Fig. 2); the *Novice* network was characterized by a single, large dimension ($\lambda = 7.85$) but the Expert network consisted of three distinct communities (Fig. 2). For Experts, Community 1 ($\lambda = 2.95$) contained the Coherence dimension (Complexity, Modernity, Order) as well as two criteria typically associated with Hominess (Personal, Comfort), suggesting that Expert participants found ordered natural environments to be comforting. The other two communities (Community 2: $\lambda = 2.97$; Community 3: $\lambda = 2.57$) contained elements previously associated with Fascination and Hominess.

Influence of underlying dimensions on overall aesthetic experience of landscapes. The co-assignment of analytic and emotional criteria to the same community for Expert participants further suggests that judgements about a space's appearance (i.e., Coherence) are more closely associated with affective responses, even for a domain distinct – but proximate to – their area of expertise. This observation was supported by EC results; the Expert network had higher EC for Complexity ($p < 0.001$), Order ($p < 0.001$), and Modernity ($p < 0.001$; SI). We also observed group differences for several other aesthetic criteria. The Expert network was characterized by higher EC for Personal ($p < 0.001$) and Hominess ($p = 0.04$) whereas the novice network had higher EC for Valence ($p < 0.001$), Comfort ($p = 0.005$), Relaxation ($p = 0.004$), and Uplift ($p = 0.004$; SI).

5. Discussion

Architecture Experts and Novices differ in their psychological responses to buildings (consistent with Study 1) *and* the natural environment (extending Study 1 results). For buildings, EGA identified several different underlying responses for Novice participants but just a single large community for Experts. The reverse effects were observed for the landscape images; the Expert network contained three communities but the Novice network was unidimensional. Although speculative, these findings suggest that training in architecture may lead individuals to more discriminately apply evaluations about composition to non-architectural domains, leading to the creation of distinct underlying dimensions. Regardless of the number of underlying dimensions, EC results supported the prediction that analytic evaluations about built and natural spaces – which fall within the Coherence dimension – had a significantly greater influence on the overall aesthetic experience of Expert participants. One plausible interpretation of these findings is that, with greater expertise, the attributes of a space's construction or physical appearance are more "deeply felt."

5.1. Study 3

Although findings from Studies 1 and 2 were consistent, there were notable limitations. First, participants came from the general population and expertise was determined using a single item self-report. Our inclusion criteria were not strict, and "expertise" was not defined with precision (i.e., the expert "cutoff point" varied from Study 1 to Study 2). Second, it is plausible that group differences stemmed from domain-general processes rather than training specific to architecture. For example, do analytic evaluations have a greater influence on overall aesthetic experience for individuals with expertise in another field that also emphasizes analytical thinking (e.g., engineering, law, or mathematics)? Finally, do expertise effects operate over judgements of differing durations? Study 3 was designed to address these limitations and open-questions. Study 3 design, analytic methods, hypotheses, and predicted results were pre-registered on the Open Science Framework prior to data collection (https://osf.io/s256y).

5.2. Method and materials

5.2.1. Participants

One hundred and eight participants (N = 102 following quality control, $M_{age} = 25.19$ years, $SD_{age} = 2.24$ years, 58.83% female, 35.29% male) were recruited from the University of Pennsylvania. Expert participants were Masters students enrolled in The University of Pennsylvania Stuart Weitzman School of Design (N = 50, $M_{age} = 24.71$ years, $SD_{age} = 1.94$ years, 54.00% female, 42.00% male). For an Architectural Novice group of participants with similar levels of education, we recruited students from The University of Pennsylvania Carey Law School (N = 52, $M_{age} = 25.65$ years, $SD_{age} = 2.38$ years, 63.46% female, 28.85% male). All participants were paid $15.00 for participation.

5.2.2. Procedure

There were two tasks in this study. For the first task (henceforth "Rapid Judgments Task"), participants viewed 64 images of buildings and 64 images of natural landscapes (same images used in Study 2) presented sequentially and in a random order. Participants had 1 s to indicate (by button-press) whether or not (i.e., "yes" or "no") they liked each image. A scrambled version of each image appeared briefly on screen after a response, followed by a fixation cross.

Following the Rapid Judgements Task, participants completed a second task that followed closely from Studies 1 and 2; participants rated 16 different images (8 of buildings, 8 of landscapes) on 16 aesthetic criteria using a sliding 7-point Likert scale (Table 1). As in Studies 1 and 2, these judgements were untimed. Given an *a priori* sample size of 100–125 participants, all Study 3 participants viewed the same 16 images. Image randomization (as in Studies 1 and 2) would have resulted in each image viewed by only a few participants, adding unwanted variability between participant responses. The 16 images included in Task 2 were selected to vary across the analytic and emotional aesthetic criteria (based on Study 2 results), with additional guidance on image selection provided by design and architecture experts (author E.G, and F.J.).

5.3. Results

Participants completed the Rapid Judgements Task before the more deliberate, untimed rating task, but we present the results in the reverse order below for ease of understanding.

5.3.1. Expertise effects on underlying psychological responses

Buildings. Broadly, we observed similar underlying psychological responses of Expert and Novice participants. EGA revealed three communities for both groups, which were largely consistent with – although not identical to – the three-dimensional structure identified in prior research (Coburn et al., 2020; Vartanian et al., 2021; Weinberger et al., 2021). Specifically, EGA identified a communities proximate to Hominess (Novice: $\lambda = 4.66$; Expert: $\lambda = 2.99$), Fascination (Novice: $\lambda = 4.40$; Expert: $\lambda = 5.62$), and Coherence (Novice: $\lambda = 1.48$; Expert: $\lambda = 1.48$; Fig. 3).

Although the overall community organization of two groups was qualitatively similar, we compared EC of the Expert and Novice networks nodes to more directly evaluate associations between aesthetic criteria (Fig. 3; SI). Consistent with Studies 1 and 2, permutation tests revealed significantly higher Novice network EC for nodes associated with the Hominess dimension (i.e., Hominess, Naturalness, Personalness, and Relation, all $p < 0.04$, uncorrected), providing robust evidence that Hominess is more relevant to the overall aesthetic experience of the built environment for individuals without formal architecture training relative to individuals with training. We did not, however, observe greater Coherence relevance in the Expert network (see SI for complete results). Instead, we found significantly higher EC in the Novice network for "Modernity" (i.e., a Coherence criteria: $p = 0.025$). This result is inconsistent with findings from Studies 1 and 2 which revealed substantially greater relevance of Coherence nodes on the Expert network.

Landscapes. For both Experts and Novices, EGA indicated the presence of a single, large community (Expert: $\lambda = 8.16$; Novice: $\lambda = 8.98$). Subsequent permutation tests revealed differences in node EC

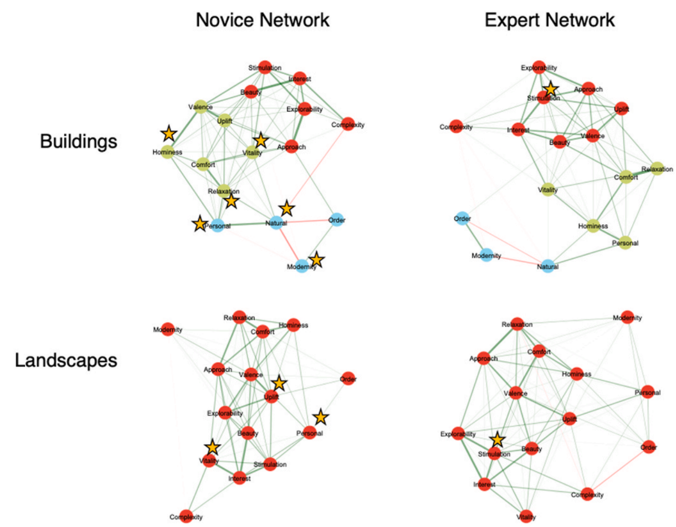

Fig. 3. Study 3 EGA Results. Graph formed from partial correlations between aesthetic rating criteria. Connectivity strength represented by edge thickness (thicker = stronger association). Red edges indicate a negative association between the criteria. Nodes that are significantly higher in eigenvector centrality (EC) for one network than another are indicated by a star. For example, Hominess EC for Buildings is significantly greater in the Novice network than in the Expert network. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

(Fig. 3; SI). Mirroring results for images of buildings, Experts exhibited greater influence of Stimulation ($p = 0.005$). EC was significantly greater for the Novices for Personal ($p = 0.008$), Uplift ($p = 0.033$), and Vitality ($p = 0.004$). Thus, consistent with findings for images of buildings, we did not observe group differences in the influence of criteria associated with Coherence (i.e., Modernity, Complexity, and Order).

5.3.2. Rapid Judgements Task

Participants had 1 s to indicate whether or not (i.e., Yes-No response) they liked 128 different images. Separate mixed-effects logistic regression models (lme4 package in R, version 1.27, binomial family; Bates, Mächler, Bolker, & Walker, 2014) were run for images of buildings and landscapes. All models included three Level 1 variables that indicated the average rating for each image on the Coherence, Fascination, and Hominess criteria (based on results of Weinberger et al., 2021). To assess whether Expert and Novice participants were differentially impacted by the underlying dimensions, we examined interactions of expertise with the Coherence, Fascination, and Hominess average ratings:

$$Rating_{Building} \sim Expertise * Fascination + Expertise * Coherence + Expertise * Hominess + (1|Subject)$$

$$Rating_{Landscape} \sim Expertise * Fascination + Expertise * Coherence + Expertise * Hominess + (1|Subject)$$

Extending findings of Studies 1 and 2, the mixed-effects model for images of buildings indicated that preferences between Expert and Novice participants – even for 1-s judgements – were differentially impacted by the underlying psychological dimensions. Specifically, Experts were significantly more influenced by Coherence (Expertise × Coherence: OR = 1.50, $t = 2.26$, 95% CI [1.05, 2.12], $p = 0.02$). By contrast, Novices preferred images higher in Fascination (Expertise × Fascination: OR = 0.47, $t = -2.58$, 95% CI [0.27, 0.83], $p = 0.01$). We also identified a main effect of Fascination (OR = 4.46, $t = 10.32$, 95% CI [3.36, 5.92], $p < 0.001$), indicating that images higher in Fascination were strongly preferred by all participants. There were no group differences for Hominess (OR = 0.94 $t = -0.23$, 95% CI [0.54, 1.62], $p =$ 0.82), consistent the previously described interpretation that this dimension may be similarly experienced across differing levels of architecture expertise. Surprisingly, we also observed a *negative* main effect of Hominess. That is participants prefer images lower in Hominess (OR = 0.43, $t = -6.04$, 95% CI [0.33, 0.57], $p < 0.001$).

For landscapes, Novices showed greater preference for Hominess (Expertise × Hominess: OR = 0.53, $t = -2.61$, 95% CI [0.33, 0.85], $p =$ 0.009), but there were no group differences for Fascination (OR = 0.87, $t = -0.55$, 95% CI [0.52, 1.45], $p = 0.58$). Intriguingly, this model also revealed a trending association between Expertise and Coherence, but in the opposite direction than observed for images of buildings (OR = 0.51, $t = -1.93$, 95% CI [0.25, 1.01], $p = 0.054$). That is, the Novice group showed a nominally greater preference for Coherence relative to the Experts.

Finally, mirroring results for building images, we also identified a positive main effect of Fascination (OR = 3.98, $t = 10.54$, 95% CI [3.08, 5.14], $p < 0.001$) and a negative main effect of with Hominess (OR = 0.55, $t = -4.93$, 95% CI [0.44, 0.70], $p < 0.001$). Separate from the questions concerning expertise, these results indicate that preferences for Fascination – for images of both buildings and landscapes – emerge within 1 s of viewing, but the impact of Hominess and varies across different time-scales (i.e., 1-s vs. untimed judgements).

6. Discussion

Findings from Study 3 were somewhat mixed. First, EGA indicated only modest qualitative differences in the underlying psychological responses of Expert and Novice for images of buildings and landscapes, in contrast with Studies 1 and 2 for which we observed variability in network organization based on expertise. We did, however, find that emotionally laden aesthetic criteria – and especially those most strongly linked with Hominess – had a significantly larger relevance for the Novice network. This result matches findings from Studies 1 and 2. By contrast, Coherence did not play a greater role in the overall aesthetic experience of Experts, inconsistent with Studies 1 and 2 as well as results from the Rapid Judgements Task.

Although Coherence did not differentially influence Experts during the untimed judgements, results from the Rapid Judgements Task did support the prediction that this dimension would be particularly salient for Experts. Specifically, when participants made 1-s judgements about the images, we found that Expert preferences were significantly more impacted by Coherence, in line with findings from Studies 1 and 2 that revealed a greater relevance of Coherence on the aesthetic experience of Experts. The observed effects during rapid judgements suggests that expertise effects emerge quickly when making aesthetic judgements (H4A). Further, the finding that Fascination was more associated with preference judgements of Novice participants – along with the main effect of Fascination on rapid judgments overall – suggests that appreciation for an environment's visual richness or interest may also emerge quickly, and may be especially relevant for the initial preferences of untrained individuals.

It is important to note that Novice participants in Study 3 were enrolled in a rigorous law program, which – like training in architecture – also emphasizes analytic thinking. The relatively small group differences observed in Study 3 during deliberate, top-down processing – especially with respect to Coherence – suggest that the influence of analytic evaluations on aesthetic experience may be based on training in analytic thinking broadly rather than training in architecture or design specifically. On the other hand, domain-specific expertise may be evident during faster evaluations (i.e., during the Rapid Judgements Task).

7. General discussion

Across three independent samples, we investigated the extent to which expertise in architecture is associated with differences in preferences and psychological responses to the built and natural environment. Consistent with recent work, we showed that aesthetic responses to images of buildings and natural landscapes can be explained by a few underlying and interconnected psychological dimensions (H1). Crucially, however, these underlying dimensions were influenced by training in architecture, such that the aesthetic networks of Expert and Novice participants differed notably (H2). We also tested the hypothesis that experts in architecture experience design features of the built environment as more emotionally and aesthetically pleasing (H3). Findings were broadly supportive of this hypothesis as well. Coherence – a dimension of aesthetic experience that more strongly captures analytic judgements about a space's features rather than to emotional response from a space – exerted a greater influence on Expert aesthetic experience during deliberate judgements in Studies 1 and 2. In Study 3, although no such effects were observed for untimed ratings, we did find that Experts' rapid, initial preferences were significantly more influenced by Coherence. Together, these results suggest that expertise can influence judgements of differing durations (H4). Specifically, domain-general differences in analytic thinking – which are relevant for architecture/design *and* law degrees – may influence deliberate untimed evaluations whereas domain-specific training (here, in architecture and design) is observable for more immediate assessments.

The present work extends research on aesthetic experiences of the built and natural environment in several ways. First, we found that participant ratings reduced to a few underlying psychological dimensions, adding to a growing list of recent work that has reported similar results (Coburn et al., 2020; Vartanian et al., 2021; Weinberger et al., 2021). Across three studies, we found fairly consistent underlying responses to the built environment for participants *without* expertise in architecture; Coherence, Fascination, and Hominess emerged as separable communities in all 3 samples for Novices. By contrast, the underlying dimensions of Experts were more variable. Study 1 Experts exhibited a 2-dimensional structure (Hominess, a combined Coherence-Fascination dimension), Study 2 Experts had a unidimensional network, and Study 3 Experts showed the more characteristic 3-dimensional organization. Thus, Coherence, Fascination, and Hominess may reflect the "typical" underlying psychological responses associated with the built environment (especially for untrained individuals), but the present findings also illustrate significant variability introduced with expertise.

We also found that Coherence – a dimension that captures analytic judgements about a space's appearance – may be more relevant to the overall aesthetic experience of experts. We argue that the differential relevance of Coherence is a byproduct of formal training in architecture and design. Specifically, education in architecture leads to changes to the operation of the knowledge-meaning system of the aesthetic triad (Chatterjee, 2014; Chatterjee & Vartanian, 2014, 2016): trained individuals are better able to understand, discern, and *appreciate* different architectural components and styles. The end result, then, is that attributes of a space's design or construction can become more "deeply felt", consistent with other perspectives in empirical aesthetics that suggest artists are more sensitive to the mastery conveyed in a painting (Bimler et al., 2019; Pihko et al., 2011), and are able to experience more nuanced emotional responses (Fayn et al., 2018). It is for similar reasons that, for Experts in Studies 1 and 2, Coherence was connected to more emotional aesthetic criteria and had a larger relevance on the overall aesthetic network (i.e., participants' overall aesthetic experience). By contrast, Coherence was fairly detached from Fascination and Hominess for Novices. Similarly, Study 3 results replicated recent work on room interiors (Vartanian et al., 2021) by showing that Expert's initial preferences for buildings (i.e., during the Rapid Judgements Task) were associated with Coherence and Novice preferences were influenced by Fascination and Hominess.

Our findings also extend a large body of empirical work and theoretical perspectives on the effects of expertise (Azemati et al., 2020;

Chamberlain, 2018; Chamberlain et al., 2019; Chamberlain & Wagemans, 2015; Fayn et al., 2018; Gartus et al., 2020; Gifford et al., 2000; Jam, Azemati, Ghanbaran, Esmaily, & Ebrahimpour, 2021; Kirk et al., 2009; Silvia, 2005, 2006; Silvia & Barona, 2009; Vartanian et al., 2019, 2021; Walker, 1980). For instance, differences in the influence of Coherence may be attributed to greater familiarity with architectural styles (i.e., mere exposure effect; Bornstein & D'agostino, 1992; Montoya et al., 2017), more context or knowledge (Kirk et al., 2009; Leder et al., 2004), or the ability to process a space's organization or complexity more fluently (Reber et al., 2004). That is, architecture experts may have greater appreciation or understanding of design features, resulting in different subjective appraisals (Ellsworth & Scherer, 2003; Lazarus, 1991; Silvia, 2005, 2006). This interpretation may accord with a recent finding that mathematicians are more appreciative of beauty in math equations (Hayn-Leichsenring et al., 2021); expertise in mathematics leads to a domain-specific appreciation of form or style (e.g., the elegance of an equation) much in the same way that expertise in architecture may cause someone to show a greater appreciate of architecture design (e.g., the order or modernity of a building). Expert architects and Novices also likely differ in "aesthetic sensitivity" – i.e., the extent to which Coherence influenced their liking or preference (Corradi et al., 2020).

Some expertise effects, however, were not consistent across all three studies. Most notably, Coherence was largely relevant to the overall aesthetic experience of Experts in Studies 1 and 2 but not in Study 3. The most likely result for this discrepancy may stem from how "expertise" was determined. For Studies 1 and 2, expertise was based on a single self-reported item administered to the general population, with Expert and Novice groups based on where individuals fell along the scale. Because we sought to have a similar number of Expert and Novice participants within each study, we used an upper and lower quartile split to create participant groups. This introduced a limitation: the threshold used to determine expertise was inconsistent from Study 1 (Expert >0 in single-item scale) to Study 2 (Expert >1.3 on single-item scale). Since Studies 1 and 2 involved different images and task conditions, we could not collapse participants across the two studies. Study 3 participants were even more qualitatively different than those of Studies 1 and 2; Experts were enrolled in an advanced architecture and design program and Novices were law students. Thus, Study 3 Experts were likely more advanced than those in Studies 1 and 2. Similarly, the Novice group in Study 3 were also highly educated, including training in a field (i.e., Law) that also emphasizes analytic and critical thinking – both of which we think influenced the relationship between Coherence and overall aesthetic experience. This is not to say that Novices in Studies 1 and 2 were uneducated, but it is unlikely that – as a whole – their respective training in analytic and critical thinking was equivalent to a group of students from one of top law programs in the United States (i.e., the Study 3 Novices). Therefore, the expertise effects of Studies 1 and 2 may have been caused by general training in analytic thinking rather than specific training in architecture. Based on this interpretation, one parsimonious account of the present findings is that domain-general differences in analytic thinking influence untimed judgements and domain-specific knowledge influences more rapid processing. Of course, "faster" and "slower" processes are interrelated in their operation (Cleeremans, 2006; Reber, 2013; Weinberger & Green, 2022), thus it would be an oversimplification to suggest that domain-general or domain-specific knowledge influences aesthetic experience at only one level. Additional research is required to tease apart the influence of domain-specific expertise from relevant influences of advanced education more broadly. Beyond these training differences, it is also plausible – though somewhat speculative – that some of the differences between Study 3 and Studies 1 and 2 may be related to demographic information; Study 3 participants were younger and – for both Novice and Expert groups – were predominantly female.

Separate from questions about expertise, findings from the Rapid Judgements Task of Study 3 yielded novel insights regarding the emergence of Coherence, Fascination, and Hominess. Most critically, participants showed a strong preference for images of both buildings and landscapes that were previously rated as high on the Fascination dimension. Thus, appreciation for visual richness and interest may develop quickly; preferences were almost immediately sensitive to the extent of Fascination conveyed in an image. Surprisingly, images of landscapes and buildings that were high on Hominess were *less* preferred during the Rapid Judgement Task. Thus, not only do characteristics of a space like personalness and comfort take more time to develop, but the initial impression conveyed by these qualities may be negative. Perhaps a Homey environment – at first glance – may be less appealing than a Fascinating space. It is only upon extended time in such spaces that their aesthetic qualities can be appreciated. Image statistics such as brightness and saturation (which were not evaluated in the present study) may play a role in these findings. However, factors such as color, contrast, and scaling were carefully controlled for during the initial creation of these stimuli (see Vessel et al., 2018), at least partially mitigating such effects.

To conclude, the present work provides strong evidence for expertise-effects on aesthetic experience of the built and natural environment. We identified variability in the underlying aesthetic experience of Expert and Novice participants, with the most substantial differences related to the overall relevance of Coherence, analytic judgements about a space's appearance. Novice participants were nonetheless able to assess a space's design features, but this evaluation occurred comparatively absent of an emotional response. Expert participants' emotional responses – as well as preferences during 1-s judgements – were more strongly tied to Coherence, indicating that training in architecture and design leads individuals to respond more strongly to qualities such as organization and complexity. Additional research is needed to more clearly identify dissociable impacts of expertise on judgements of differing durations. To improve ecological validity, such work would ideally be conducted in real-world environments. Finally, these results point to a potential tension between architects and their clients. Architects might experience the spaces they design differently than the people for whom these spaces are designed.

Author note and data availability

The authors declare no competing interests. Data, code, and preregistration supporting the manuscript are publicly available on the Open Science Framework at: https://osf.io/a3k7x/.

Author contributions for

Adam B. Weinberger: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, visualization. **Eleanor W. Garside**: Conceptualization, Investigation, Writing – review & editing. **Alexander P. Christensen**: Formal analysis, Writing – review & editing. **Anjan Chatterjee**: Conceptualization, Writing – review & editing, supervision, funding acquisition.

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Appendix A. Supplementary data

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