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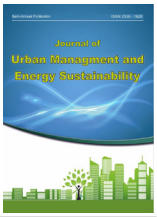

ORIGINAL RESEARCH PAPER

Explaining the Evaluation Indicators of the Concept of the Role of Shadowing on the Perception of Form in Architecture

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ABSTRACT

Cast shadow is among the most pervasive yet least systematically evaluated phenomena in architectural form, usually treated as a secondary or merely functional matter rather than as an active determinant of how form is perceived. The central problem addressed in this study is the absence of an explicit, validated set of evaluation indicators that capture how the dynamic play of cast shadow modulated by the texture and colour of facade materials shapes the perception of architectural form. The objective of this research is therefore to explain and validate the evaluation indicators of the role of shadowing on the perception of form, and to model the relationships among them. Adopting a mixed-methods design built on methodological triangulation, the study combined qualitative content analysis of 57 specialist documents in MAXQDA (yielding 179 sub-codes, eight main categories, and two core codes), a three-round Fuzzy-Delphi expert consensus that reduced 22 initial factors to ten high-importance indicators, and partial-least-squares structural-equation modelling in SmartPLS on 200 valid questionnaires. Findings indicate that cast shadow operates as a key mediating variable that enables form perception through the dialectical interaction of two constructs “volumetric structure” (the static dimension) and “time passage” (the dynamic dimension) between which the quantitative model found a very strong relationship ($\beta = 0.965$). Volumetric structure exerted strong, significant effects on design components ($\beta = 0.928$), materials and texture, homogeneity, contrast, texture and visual richness, and visual-perception analysis, while time passage drove surface-height change and spatial mode-setting . The study concludes that optimal form perception depends on designing simultaneously for structural stability and temporal change, and it offers a validated indicator set and a perceptual-dynamics evaluation framework that move facade assessment from intuition toward evidence.

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INTRODUCTION

The perception of architectural form is never a perception of geometry alone. Form becomes visible only through light, and light becomes legible only through the shadows it casts. (Bertamini et al., 2018) Cast shadow the dark figure thrown by a projecting or receding element onto a surface is the medium through which the eye reads depth, relief, rhythm, scale, and weight in a building. Yet in much of the literature and in everyday practice, shadow is regarded as an incidental by-product of massing and orientation, or is reduced to a purely functional concern of solar control, rather than being recognised as an active variable in the perception of form. (Rezaei et al., 2020, Ringle et al., 2012, Roger and Graham, 1979) This neglect leaves a concrete gap: there is no explicit, validated set of evaluation indicators that captures how the dynamic behaviour of cast shadow shapes the perception of form, and how the texture and colour of facade materials modulate that behaviour. Without such indicators, the assessment of a facade's perceptual quality remains intuitive and unaccountable, and the designer has no evidence-based instrument with which to predict or steer the perceptual experience a form will deliver as light changes through the day. (Strauss and Corbin, 1998, Tabrizian et al., 2018, Tenenhaus et al., 2005, Strømann-Andersen and Sattrup, 2011) The present study addresses this gap directly by explaining and validating the evaluation indicators of the role of shadowing on the perception of form, drawing on the analytical and conclusive findings of a doctoral investigation that combined qualitative content analysis, Fuzzy-Delphi expert consensus, and structural-equation modelling. (Casati, 2004, Wagemans, 2012, Unwin, 2009) The guiding research question is how cast shadow influences the perception of form, and how changes in facade materials (texture and colour) moderate that influence. (Charmaz, 2006, Zumthor, 2006, Wong, 2017) In answering it, the study reconceives form not as a static object but as a time-dependent perceptual process, and shadow not as a decorative residue but as a central design construct whose governing rules can be identified, measured, and applied. This article focuses on the analytical results and the resulting theoretical and practical framework the core contribution of the underlying research and presents them as a coherent set of evaluation indicators for the role of shadowing in the perception of architectural form.

Form, light, and shadow in architectural perception

The concept of form has one of the longest and most contested histories in aesthetics, ranging from the classical identification of form with the harmonious ordering and proportion of parts to the modern reading of form as an actively perceived, dynamic quality. Across this history, the visibility of form has been understood to depend on light: light is the hosting medium through which form is brought to appearance, and in the Iranian architectural tradition in particular, the interplay of light and darkness the deliberate use of shadow to affirm and reveal light has been a primary expressive device. (Dee and Santos, 2011) Cast shadow is the concrete trace of this interplay, the phenomenon in which the geometry of a surface, the direction of light, and the passage of time jointly produce a legible, changing figure on the building. A body of perceptual research establishes that cast shadows are an effective ordinal cue for depth position and a powerful aid to the recognition of three-dimensional structure. Studies of cast-shadow perception show that increasing the separation between a contour and its cast shadow improves the recognition of depth position, that the visual system assumes light comes from above when interpreting shadows, and that cast shadows remain an effective depth cue even under considerable local jitter. (Cucker, 2013, Elder et al., 2004, Hair et al., 2017) Work on the spectral behaviour of shadow further shows that shadow depth can be quantified through

a normalised spectral signature. Together this literature confirms that shadow is not visual noise but a structured carrier of spatial information precisely the premise on which an indicator-based evaluation of shadowing can be built. The surface on which a shadow falls is not neutral. (Dewey, 2005, Henseler et al., 2009, Hsu et al., 2010, Kersten et al., 1997) The texture and colour of facade materials act as the receiving and reflecting ground of light, modulating the physical characteristics of the shadow the sharpness of its edges, its degree of darkness, the texture within it and thereby its perceived qualities of depth, weight, and richness. (Mamassian et al., 1998, Mardaljevic et al., 2009, Martinelli, 2015) A rough, deeply worked stone absorbs light into its cavities and produces deep, soft-edged shadows that connote age, solidity, and nature; a polished metal sheet produces a restless, minimal, high-contrast shadow that connotes technology and weightlessness. Material choice is therefore not a decorative skin over structure but the selection of a particular "dialect" in which the form's shadows will speak a premise that motivates including texture and material among the evaluation indicators. (Ramachandran, 1988, Pallasmaa, 2012, Norberg-Schulz, 1980) Taken together, these strands establish three expectations that the present study operationalises and tests: that the volumetric structure of a form is the principal generator of its perceptually significant shadows; that the passage of time, by continuously changing light, converts a static form into a sequence of perceptual events; and that facade materials mediate the translation of geometry into legible shadow. The study's contribution is to convert these expectations into a validated set of evaluation indicators and a measured structural model.

MATERIALS AND METHODS

Methodology

The study adopts an analytical–applied design within a post-positivist, mixed-methods paradigm, built on methodological triangulation across three complementary strands: qualitative content analysis, Fuzzy-Delphi expert consensus, and partial-least-squares structural-equation modelling. The triangulation allows the evaluation indicators to be first discovered inductively, then filtered by expert judgement, and finally validated quantitatively against survey data, so that the resulting indicator set is grounded simultaneously in the literature, in professional expertise, and in measured perception. In the first strand, 57 specialist documents were analysed in MAXQDA through open, axial, and selective coding. The process yielded 179 sub-codes, which were consolidated into eight main categories among them shadow and energy, spatial mode-setting, spatial perception, shadow and surface, formal structure, and viewing distance and ultimately into two core codes, "time passage" and "volumetric structure." The emergence of these two core codes, one dynamic and one static, established the central dialectic that the rest of the study tested and elaborated. In the second strand, a three-round Fuzzy-Delphi procedure with expert participation reduced an initial pool of 22 candidate factors to ten final high-importance indicators: volumetric structure, time, light direction, surface change, viewing distance, symmetry, homogeneity, contrast, depth, and texture. These ten indicators, with volumetric structure and time carrying the highest consensus importance, formed the basis of the quantitative questionnaire. Their importance ranking is shown in (Fig. 1).

In the third strand, the conceptual model derived from the qualitative phase was tested by partial-least-squares structural-equation modelling in SmartPLS, using 200 valid questionnaires measured on a five-point Likert scale. PLS-SEM was selected because the model was a newly generated conceptual model, the data were non-normal, some constructs had fewer than three indicators, and the model was complex conditions under which variance-based SEM is the appropriate method. Sampling adequacy was confirmed (KMO = 0.890; Bartlett's test significant

at the 99% level), and skewness and kurtosis fell within the ±3 and ±5 thresholds, confirming acceptable distribution. The measurement (outer) model was first purified by removing indicators with factor loadings below the 0.65 threshold, after which reliability and validity were established before the structural (inner) model was used to test the hypotheses. The full conceptual model is shown in (Fig .2).

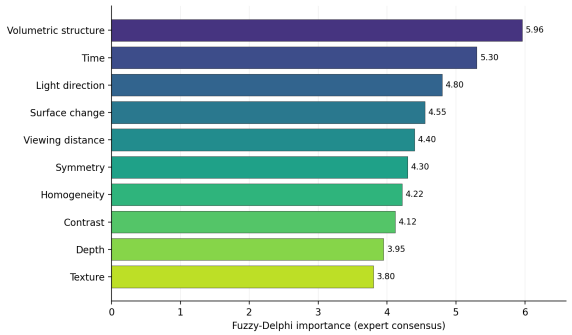

Figure 1: The ten final evaluation indicators of the role of shadowing on form perception and their Fuzzy-Delphi importance, with volumetric structure and time the most important (source: author, from the dissertation's Fuzzy-Delphi results).

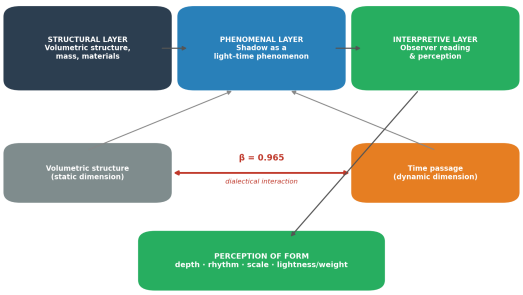

Figure 2: Conceptual model of the role of shadowing on form perception: shadow as a three-layer dynamic semiotic system driven by the dialectic of volumetric structure and time passage (β = 0.965) (source: author).

FINDINGS AND DISCUSSION

The findings are organised around the measurement model (the reliability and validity of the evaluation indicators) and the structural model (the relationships among them), reflecting the analytical core of the study.

Reliability and validity of the indicators

The purified measurement model demonstrated strong reliability and validity across all constructs. Cronbach's alpha, composite reliability (Dillon–Goldstein's rho), and the non-parametric rho_A all exceeded the 0.70 threshold for every construct, and the average variance extracted (AVE) exceeded 0.50 throughout, with composite reliability exceeding AVE in every case jointly confirming convergent validity. The two core constructs were measured with particular precision: volumetric structure reached a composite reliability of 0.982 (AVE 0.728) and time passage 0.977 (AVE 0.723). The reliability and validity profile is summarised in (Fig. 3) and Tab. 1)

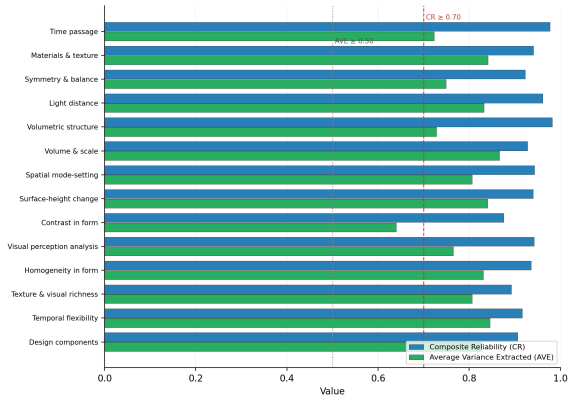

Figure 3: Composite reliability (CR) and average variance extracted (AVE) for the fourteen model constructs; all CR ≥ 0.70 and all AVE ≥ 0.50 (source: author, from the dissertation's PLS-SEM output).

The structural model: volumetric structure as the static driver

The structural model confirmed that volumetric structure is a dominant driver of the design and perceptual constructs. Its standardised path coefficients were very strong and significant: to homogeneity in form (β = 0.959), to materials and texture (β = 0.934), to design components (β = 0.928, T = 121.71), to contrast in form (β = 0.901), to visual-perception analysis (β = 0.886), and to texture and visual richness (β = 0.840, T = 49.99). These coefficients establish that the

nature of the volumetric structure dictates the quality, variety, and arrangement of design components and the language of the materials that express it, fully supporting the hypothesis that volumetric structure is co-directional with visual richness and perception. The coefficients are shown in (Fig. 4).

Table 1: Reliability and convergent-validity indices for the principal constructs (source: author, from the dissertation; "—" denotes values not separately tabulated).

Construct	Cronbach α	CR	AVE
Volumetric structure	—	0.982	0.728
Time passage	0.974	0.977	0.723
Homogeneity in form	0.901	0.936	0.831
Visual perception analysis	—	0.942	0.765
Materials & texture	0.905	0.941	0.841
Surface-height change	—	0.940	0.840
Spatial mode-setting	—	0.943	0.806
Light distance	—	0.961	0.832
Contrast in form	—	0.876	0.640
Texture & visual richness	0.768	0.892	0.806

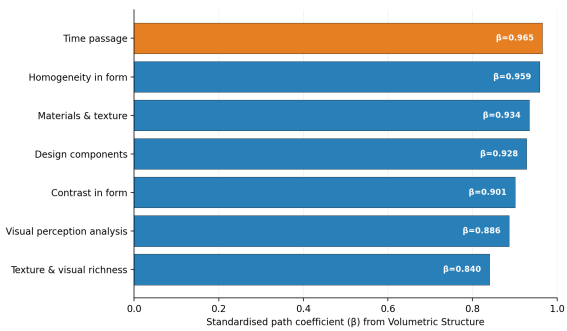

Figure 4: Standardised path coefficients (β) from volumetric structure to the design and perceptual constructs, and to time passage (orange); all relationships strong and significant (source: author, from the dissertation's PLS-SEM).

The structural model: time passage as the dynamic driver

Time passage was confirmed as the dynamic driver that activates the perceptual potential of the form. It exerted very strong effects on surface-height change (β = 0.957) and on spatial mode-setting with shadow and light (β = 0.943), establishing that a physically fixed feature such as a change in surface height delivers its perceptual effect only as a function of the time of day at which it is observed. Time thus converts the form into a perceptual event experienced as a meaningful sequence rather than a single ideal instant. These effects are shown in (Fig. 5).

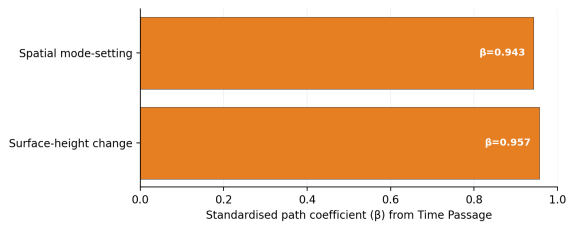

Figure 5: Standardised path coefficients (β) from time passage to surface-height change and spatial mode-setting (source: author, from the dissertation's PLS-SEM).

The central dialectic and the role of materials

The single most important structural result is the very strong relationship between volumetric structure and time passage (β = 0.965), which substantiates the central thesis that matter and time are inseparable constituents of the being of form. Materials act as the interpretive ground that translates the geometric language of the structure into the optical language of shadow:

the strong path from volumetric structure to materials and texture (β = 0.934) shows that a change of material is not a decorative skin but a fundamental change in the structural language of expression. The significant, moderate correlation between volumetric structure and light depth (r = 0.379, p = 0.0036) confirms that rich volumetric structure is a necessary but not sufficient condition for strong perceived depth, whose final quality depends on the interaction of structure with the reflection and absorption properties of the material surface.

Table 2: Results of the three research hypotheses (source: author, from the dissertation).

Hypothesis	Statement (abbreviated)	Result
H1	Volumetric structure is co-directional and significant with design components, visual richness, and perception	Strongly confirmed
H2	Intensity/direction of the shadow effect via volumetric structure is a function of form complexity and novelty	Conditionally / qualitatively supported
H3	Change of material alters the perceived depth of cast shadow on the form	Decisively confirmed

The first hypothesis that volumetric structure is co-directional and significant with design components, visual richness, and perception was strongly confirmed by the path coefficients above. The third hypothesis that a change of material alters the perceived depth of cast shadow — was decisively confirmed through the chain: change of material → change in surface properties (texture/colour) → change in the quality of shadow display (contrast, edge) → change in perceived depth. The second hypothesis — that the intensity and direction of the effect depend on form complexity and novelty — was supported conditionally and qualitatively, since the strength of the volumetric-structure effect differed across constructs (for example, the weaker path to texture and visual richness, β = 0.840, and the non-significant initial relationship with visual balance), indicating that a direct quantitative measure of geometric complexity should be introduced as a moderator in future work.

RESULTS AND CONCLUSION

The study set out to explain the evaluation indicators of the role of shadowing on the perception of architectural form, and it concludes that cast shadow is a dynamic semiotic system that enables form perception through three chained layers a structural layer (geometry, mass, materials), a phenomenal layer (shadow as a light–time phenomenon), and an interpretive layer (the observer's reading) driven by the dialectic of volumetric structure and time passage. Every projection, recess, surface change, and material change is a potential meaning-bearing unit; the passage of time and the changing light activate these potentials into actual signs (specific shadows of definite size, direction, and quality), which the observer interprets as depth, sequence, scale, rhythm, lightness, and weight. Four theoretical contributions follow. First, the study formulates a paradigm of dynamism in form perception, recasting form from "an object to be seen" into "a process to be experienced," with the strong volumetric-structure–time relationship (β = 0.965) confirming that matter and time are inseparable constituents of form. Second, it redefines the role of materials, raising them from a structural or decorative skin to active mediators that constitute the interpretive ground of shadow. Third, it articulates a hierarchical, networked causal structure in which volumetric structure and time passage are the primary drivers that activate intermediate variables (surface-height change, spatial mode-setting, contrast), which in turn shape the final perceptual qualities. Fourth, it revives the concept of organic wholeness unity in multiplicity as the

condition of rich, meaningful perception. On the practical side, the study yields a perceptual-dynamics evaluation framework: a prioritised set of ten design indicators; a combined qualitative–quantitative scoring sheet that converts each indicator into objective items and produces a perceptual-dynamics rating (PDR) for a facade; shadow-sensitive urban-design strategies based on dynamic view-shed analysis; and guidance for selecting facade materials according to their shadow performance. Together these move facade design and assessment from pure intuition toward an evidence-based, predictable process.

The doctrine: architecture as a time-bound apparatus for producing experience

The doctrine governing the research is "architecture as a time-bound apparatus for producing experience," resting on five pillars (Figure 6). The first is a paradigm shift from object-centred to event-centred architecture: the work is an unfinished potential actualised only through the active interaction of natural light and a moving observer, so the architect is a director of time and light, not merely a designer of forms. The second is the architect's perceptual responsibility the obligation to be conscious of the perceptual messages of the work, since the strong paths from volumetric structure to spatial mode-setting ($\beta = 0.943$) and visual-perception analysis ($\beta = 0.886$) confirm that architecture communicates through the language of light and shadow. The third is perceptual efficiency, which calls for maximising the richness of aesthetic and meaningful experience with minimal material resources, set alongside thermal and technical efficiency. The fourth is a relational aesthetics in which beauty is not an intrinsic property of form but the outcome of a dynamic network of relations among form, sky, ground, time, and observer. The fifth is holistic unity unity in multiplicity as the basis of rich perception and of a perceptual sustainability that complements energy sustainability. The fundamental rule extracted from the research is therefore that optimal perception of form depends on designing simultaneously and co-directionally for structural stability and temporal change, with materials acting as the active interpreter that translates the geometric language of structure into the optical language of shadow. Understood this way, architecture is the art of organising light and time in the medium of matter.

Limitations and future research

The study is subject to limitations that also define its future directions. The qualitative analysis rested on existing texts and documents rather than systematic field measurement; the questionnaire relied on self-report and recall rather than in-situ response; the quantitative data were cross-sectional, warranting caution in inferring causality; and the scope was confined to building facades viewed externally, excluding interior shadow experience. Future research should develop integrated digital tools (for example, plug-ins in Rhino/Grasshopper or Revit that compute dynamic shadow indicators and return immediate feedback), conduct controlled laboratory and field studies using physical or virtual-reality models with neuro-architectural measurement (eye-tracking, EEG), extend the framework to the urban and landscape scale, examine cross-cultural differences in shadow interpretation, and integrate dynamic perceptual indicators into sustainability rating systems such as LEED and BREEAM so that the quality of visual experience over the day is counted among occupant-wellbeing criteria.

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