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Kansei Engineering-Based Framework for the Material-Driven Design of Pietra Serena Urban Furniture

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Abstract

Despite the historical significance of indigenous materials, modern urban furniture design often suffers from a perceptual gap, namely a lack of a systematic bridge between raw materiality and human emotional response. This research proposes a novel Material-Driven Design (MDD) framework that integrates Kansei Engineering (KE) with Structural Equation Modeling (SEM) to examine the sensory-psychological impact of *Pietra Serena*. Drawing inspiration from the stone's legacy in Renaissance architecture, such as Michelangelo's Laurentian Library, the study employs a mixed-methods approach. Initially, Kansei descriptors were extracted from a preliminary group (n=46), followed by a large-scale survey (n=300) conducted in Florence, Italy, evaluating ten bench prototypes via a 7-point Semantic Differential (SD) scale. Data were analyzed using a formative measurement model in Smart-PLS, demonstrating strong explanatory power ($R^2 > 0.99$). The results indicate that structural-geometric morphology, in combination with flamed textures, is strongly associated with perceived Minimalism (K3 = 0.803) and Authenticity (K1 = 0.659). The study further develops a Kansei-based design framework that translates the identified material-form relationships into mathematical equations to support the interpretation and application of Kansei responses in urban furniture design. This framework provides a context-specific approach for municipalities and designers to explore indigenous mineral resources through the integration of cultural heritage, material characteristics, and evidence-based design.

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Introduction

The intersection of material essence and human perception defines the fundamental character of urban environments. In the fabric of historical and contemporary cities alike, the choice of materials transcends mere structural necessity, acting as a profound medium for cultural expression and aesthetic experience. While the classical tradition emphasized a holistic harmony between materiality and the human spirit, modern urban development often prioritizes functional utility over sensory and emotional resonance. This shift has created a disconnection in how we perceive and interact with the physical elements of the city. To address this gap, it is essential to revisit the philosophical roots of material beauty and re-evaluate them through the lens of modern computational analysis. By bridging the historical narratives of material dignity Kansei Engineering-Based analytical frameworks, we can reclaim a more conscious and human-centric approach to urban design.

1.1 The Metaphor of Serena: From Dante to Design

"*Io son dolce Serena, Che' marinari in mezzo mar dismago*." (I am the sweet *Serena*, who bewitches sailors in the mid-sea) *(Alighieri, 1308–1320/2003)*. This evocative metaphor from Dante Alighieri's *Divine Comedy* speaks to a magnetic attraction rooted in perception, manifesting as a visceral pull that, centuries later, found its physical manifestation in the gray, dignified silhouette of *Pietra Serena*. This material is far more than a mere geological entity; it is a cultural vessel that has long symbolized the enduring dignity and stability of the Renaissance.

This pursuit of material dignity transcends mere intuitive attraction, finding its anchor in a rigorous intellectual framework of beauty. Central to this aesthetic is the principle of *Concinnitas*, championed by Leon Battista Alberti *(1452/1988)*, who conceptualized beauty as a seamless harmony of all constituent parts, where any addition or subtraction would compromise the integrity of the whole. Such a philosophy epitomizes the broader architectural tenets of the Age of Humanism *(Wittkower, 1971)* and underscores a significant trajectory within the historical evolution of architectural theory *(Trachtenberg, 1986)*. Within the Renaissance urban fabric, the deliberate selection and proportioning of *Pietra Serena* served as a strategic orchestration to realize this cosmic balance. In the contemporary era, however, the nuanced understanding of material-driven beauty has largely given way to utilitarian efficiency, precipitating a critical perceptual gap. This deficiency in the systematic connection between raw materiality and human emotional response is precisely what the present study aims to rectify through the implementation of a Material-Driven Design framework supported by Kansei Engineering.

1.2 The Problem: The Perceptual Crisis in Modern Urban Spaces

In the contemporary era, cities function as intricate perceptual environments where the quality of life is shaped more by the overarching psychological atmosphere than by mere utilitarian infrastructure. Urban furniture, as the most intimate interface between the individual and the urban fabric, plays a pivotal role in mitigating the pervasive anonymity of public spaces. However, modern urbanism is currently defined by a crisis of featureless uniformity. This perceptual gap is a direct consequence of a reductive functionalist approach to materials, which overlooks the emotional affordance provided by indigenous resources, specifically the geological and petrographic characteristics of the local lithic resources in Tuscany *(Pecchioni et al., 2014; Garzonio et al., 2010)*. Although the paradigm of Biophilic Design recognizes the capacity of natural materials to bolster mental health, the exact mechanism for translating these tactile properties (such as texture, grain, and porosity) into measurable emotional experiences has remained an unmodeled void. This gap is particularly evident in the phenomenological understanding of urban space, where the intimacy of material and the poetics of the environment *(Bachelard, 2008)* shape the inhabitant's psychological refuge *(Appleton, 1975)* through a complex process of sensory integration *(Ayres, 2005)*.

1.3 Bridging the Gap: Kansei Engineering as a Translation Tool

The central challenge in reconciling material science with aesthetic experience lies in the transition from intuitive design to Kansei Engineering-based design. The critical question is how abstract, high-order qualities (such as authenticity, dignity, or serenity) can be extracted from the subjective realm of human perception *(Norman, 2004; Schütte, 2005)* and translated into a technical, repeatable, and quantifiable language. To bridge this divide, the present study utilizes Kansei Engineering (KE). As a consumer-oriented framework, KE provides a systematic methodology to translate the qualitative nuances of human emotion into the quantitative parameters required for engineering and design *(Harada, 1998; Nagamachi, 1995)*, thereby transforming subjective feelings into actionable technical data. Specifically, such an approach has been successfully applied to optimize the form design of urban street furniture *(Luo et al., 2012)*, with the selection of prototypes further aligned with standard ergonomic and material guidelines for urban furniture *(Neufert, 2014)*. Furthermore, recent evidence highlights the effectiveness of KE in analyzing the emotional responses triggered by the texture perception of natural stone surfaces *(Hao & Wang, 2023)*, establishing a direct empirical link between the tactile attributes of lithic materials and human affective experience. The integration of a Japanese computational framework within a European architectural context is not merely a methodological choice, but a cognitive synthesis that bridges the holistic-contextual perception of the East with the analytic-structural tradition of the West *(Nisbett, 2003)*.

1.4 Research Objectives and Innovation

The primary objective of this research is to examine the structural relationships between the physico-material attributes of *Pietra Serena*, as a material distinguished by its specific quality standards and sustainability profile within the Tuscan architectural tradition *(Garzonio et al., 2010)*, and the affective perceptions of urban dwellers. This study introduces a three-fold innovation to the field of urban design. Methodologically, it pioneers the integration of Kansei Engineering (KE) with Formative Structural Equation Modeling (Smart-PLS) *(Kline, 2023; Henseler et al., 2014)* specifically within the context of lithic urban furniture. Theoretically, this research extends the application of the KE framework *(Nagamachi, 1995; Lévy et al., 2004)*, traditionally applied to industrial consumer products such as automotive and electronic design, to the study of structural material perception at an urban scale. Practically, the study develops a Kansei Design Matrix (KDM) as a strategic instrument for designers to relate material and morphological parameters to users' affective perceptions. By synthesizing Renaissance art history with Japanese engineering methodology, this research demonstrates how a material-focused approach can support a more conscious and context-sensitive design process, highlighting the potential of indigenous materials to contribute to a meaningful Sense of Place in the contemporary city.

Literature Review

The conceptualization of materiality in urban design has evolved from a purely technical consideration of durability and cost toward a profound exploration of human experience and sensory engagement. This literature review systematically examines the theoretical landscape, moving from the philosophical underpinnings of material phenomenology to the biological imperatives of biophilic design. By analyzing the existing discourse on how materials communicate meaning and evoke emotional responses, this section aims to identify the systemic limitations of current qualitative frameworks. The objective is to situate the present study within the ongoing effort to formalize the relationship between tactile qualities and human perception, thereby providing the theoretical justification for a quantitative Kansei Engineering-based approach.

2.1 The Phenomenology of Material: From Haptic Perception to Biophilia

Contemporary design theory has experienced a profound paradigm shift, evolving from a predominantly form-centric discourse *(Ching, 2014)* toward a material-driven ontological perspective. Pallasmaa *(1996, p. 31)* posits that natural materials, particularly stone, evoke a haptic intimacy that anchors the individual within the historical and spatial continuum of an environment. This perspective is further corroborated by the tenets of Biophilic Design, rooted in the innate human affinity for natural systems *(Wilson, 1984; Zhang et al., 2022)*, which demonstrate that engagement with natural textures significantly mitigates cortical stress and fosters restorative urban experiences *(Kaplan & Kaplan, 1989)*. Despite these theoretical foundations, current Material-Driven Design (MDD) frameworks *(Karana et al., 2015)* continue to rely predominantly on qualitative interpretations. Consequently, a critical void persists: the absence of a rigorous mathematical bridge capable of synthesizing the sensory layer, comprising texture and morphology, with the perceptual layer of human emotion.

2.2 Kansei Engineering (KE): Decoding the Emotional Vocabulary

Kansei Engineering (KE), conceptualized as a translational science by Mitsuo Nagamachi *(1995)* and theoretically refined by Harada *(1998)*, offers a systematic methodology for operationalizing subjective emotional responses into precise design specifications. Although KE has been extensively utilized in high-precision industries (such as automotive and fashion design) to optimize consumer satisfaction *(Nagamachi, 2015)*, its application to urban furniture and natural lithic materials remains relatively nascent. Moving beyond the predominantly visual-perceptual focus of existing KE studies, this research expands the framework by integrating Tactile-Spatial Affordances at an urban scale. In this context, the perceived nobility and affective quality of *Pietra Serena* are not merely described qualitatively, but are systematically decoded into specific morphological parameters *(Nagamachi & Bechter, 2020)*. This approach is supported by evidence regarding the correlation between surface roughness and emotional response *(Choi & Jun, 2007)*, establishing a robust foundation for the application of Formative Structural Equation Modeling *(Chin, 1998)*. Such a transition from intuitive design to a systematic analytical approach necessitates a rigorous translation of emotional values into technical specifications *(Schütte, 2005)*. While traditional KE has been successfully applied to a wide range of products, including the optimization of vehicle *interiors (Schütte & Eklund, 2005)*, recent advancements have integrated deep learning and advanced statistical methods to enhance the precision of these models *(Zhang et al., 2021)*.

Methodology

To bridge the gap between qualitative sensory perception and quantitative material analysis, this research employs a Mixed-Method Exploratory–Quantitative strategy. This dual-stage approach is designed to capture the nuances of human emotional responses while providing a systematic basis for quantitative analysis. The core of the methodology is built upon Hybrid Kansei Engineering (HKE), which facilitates the translation of subjective emotional impressions (Kansei) into measurable design parameters. By integrating HKE with Formative Structural Equation Modeling (SEM), the study examines the relationships between the material's physical properties and perceived emotional responses.

The methodological framework is operationalized in two primary phases: (1) an Exploratory Phase, focusing on the synthesis and refinement of the semantic emotional space through qualitative analysis; and (2) a Quantitative Phase, utilizing data from the larger participant sample to examine the identified factors and their relationships within the structural model. This systematic progression ensures that the resulting design guidelines are grounded in empirical evidence and statistical analysis rather than solely on intuitive assumptions.

3.1 Phase I: Qualitative Exploration (Kansei Synthesis)

The initial phase focused on the construction of the emotional semantic space. This process commenced with a lexical repository comprising 34 initial adjectives, identified through an extensive review of literature in Environmental Psychology and Aesthetics and preliminary exploratory work. To refine these descriptors and examine their cultural and contextual relevance, an open-ended association study was conducted with 46 participants in Florence, Italy (54% female, 46% male). This preliminary sample provided an exploratory basis for identifying terms associated with perceptions of *Pietra Serena* urban furniture. Through an iterative refinement process supported by Harada's Scatter Plot method (*Harada et al., 2001*), the initial pool of 34 adjectives was reduced to 10 key attributes by eliminating overlapping and highly similar descriptors.

A subsequent quantitative study was conducted with a larger sample of 300 participants in Florence. Participants evaluated images of the bench designs using the selected attributes and a 7-point Semantic Differential scale. Each of the 300 participants evaluated all ten bench alternatives (B1–B10) and all three *Pietra Serena* texture alternatives (T1–T3) through a structured questionnaire. High-resolution images of the stimuli were presented under a consistent evaluation procedure, and participants assessed each stimulus using the five Kansei factors (K1–K5) on a 7-point Semantic Differential scale. The bench and texture alternatives were treated as observed design stimuli rather than latent indicators, while the Kansei factors represented the affective dimensions evaluated by the participants. Thus, the dataset consisted of repeated evaluations of the stimuli by the same participants. The main sample was recruited using a stratified random sampling approach. Demographic characteristics, including age and gender, were recorded to describe the composition of the sample. The larger sample enabled further examination and refinement of the initial 10 attributes, resulting in five core Kansei Factors: Authenticity (K1), Aesthetics (K2), Minimalism (K3), Ergonomics (K4), grounded in the principles of human factors and anthropometry (*Tilley, 2001*), and Safety/Hygiene (K5). The selection of the stone's physical properties was further supported by standard geological classifications (*Tarbuck & Lutgens, 2017*).

Following the operationalization of these factors, the stimuli for the primary experiment were established. These stimuli were derived from a curated selection of 16 works by renowned sculptors and designers, exhibited at the Milan Triennale (*1997*) under the thematic exhibition *Art in the City: The Stone Chair*, an initiative supported by the municipality of Firenzuola and the COGIVAS consortium (*Stolzuoli, 2018, pp. 24–25*). From this ensemble, ten bench prototypes (B1–B10) were selected to provide morphological diversity (see Figure 1). Importantly, the prototypes were presented to participants without predefined morphological labels or categories. The subsequent morphological grouping emerged from the analysis of participants' evaluations rather than being imposed a priori by the researchers.

Figure 1: *Morphological diversity of the selected bench prototypes (B1–B10)* (Stolzuoli, 2018, pp. 24-25).

To isolate the tactile dimension as a critical variable, three standardized surface treatments of *Pietra Serena* were selected: Polished (T1), Bush-hammered (T2), and Flamed (T3), following the textural classifications established by Bargossi et al. *(2002, p. 132)*, as illustrated in Figure 2. The technical selection of these samples was further validated through standardized tests for absorption and bulk specific gravity *(ASTM International, 2020)* and grounded in the geological profiles of the Florentine quarries *(Bastogi & Fratini, 2004)*. This ensures that the materials selected not only reflect the authentic lithic composition of the city's historic core *(Coli et al., 2008)* but also meet contemporary sustainability and Life Cycle Assessment (LCA) benchmarks *(Bovea et al., 2009)*.

Figure 2: *Tactile samples of Pietra Serena textures: (T1) Polished, (T2) Bush-hammered, and (T3) Flamed*

(Bargossi et al., 2002, p.132).

3.2 Phase II: Quantitative Assessment (PLS-SEM Approach)

To provide an adequate basis for the PLS-SEM analysis, a stratified random sample comprising 300 urban dwellers in Florence was assembled, consisting of 193 females (64.3%) and 107 males (35.7%). Each participant evaluated all ten bench alternatives (B1–B10) and the three *Pietra Serena* texture alternatives (T1–T3) through a structured questionnaire using a 7-point Semantic Differential (SD) scale across the five Kansei factors. High-resolution images of the stimuli were presented under a consistent evaluation procedure; therefore, the stimuli were assessed as visual-perceptual design alternatives rather than through direct physical or tactile interaction.

From a measurement perspective, the relevant form and texture attributes were specified as formative indicators because they contribute to and collectively define the corresponding aggregate constructs. This specification follows the principles for formative measurement models described by Hair et al. (*2017*) and Henseler et al., in which indicators are understood as contributors to the construct rather than interchangeable manifestations of an underlying latent trait.

3.3 Statistical Analysis in Smart-PLS

Data analysis was performed using SmartPLS 4.0 following a systematic two-stage evaluative framework. The first stage focused on the assessment of the formative measurement model, with particular attention to outer weights, outer loadings, collinearity (VIF), and their statistical significance. The indicators were assessed according to established criteria for formative measurement models, with particular consideration given to the magnitude and significance of outer weights, the relevance of outer loadings, and the absence of critical collinearity.

Subsequently, the structural model was evaluated using a bootstrapping algorithm with 5,000 subsamples to assess the statistical significance and stability of the estimated relationships. Path coefficients (β) were used to examine the strength and direction of the structural relationships, while outer weights (W) were used to determine the relative contribution of each physical feature to the corresponding Kansei factor. Based on these statistical results, the model was systematically refined to retain the indicators demonstrating the most meaningful contributions and relationships. Finally, the explanatory power of the structural model was assessed using effect size (f^2) and the coefficient of determination (R^2).

3.4 The Kansei-Based Design Formulation

The final phase of the methodology focused on translating these statistical outputs into a design-oriented formulation. By extracting the Outer Weights (W_ij) from the PLS-SEM model, a mathematical formulation was developed to quantify the relative Kansei contribution of a specific material-form combination. The formulation is expressed as a weighted linear combination, in which the Kansei score (K_j) is calculated as the sum of the products of each physical feature's value and its corresponding weight:

$$KS\_i = \sum_{j=1}^{n} (W\_ij \times F\_j)$$

Where X_i represents the normalized value of the physical attribute and W_ij denotes the weight of that attribute for the j-th Kansei factor. This formulation transforms the qualitative perception of "material dignity" into a quantifiable measure, enabling designers to examine the relationship between physical parameters on the derived weights.

Results and Statistical Analysis

This section presents the empirical findings derived from the PLS-SEM analysis, moving from the theoretical conceptualization of material perception to its quantitative examination. The objective is to systematically examine how the proposed framework represents the relationships between physical features of urban furniture and users' Kansei responses. The analysis is structured in two stages: first, the assessment of the Measurement Model to examine the the statistical adequacy of the formative indicators; and second, the evaluation of the Structural Model to assess the strength and significance of the relationships between physical features and Kansei dimensions. By applying established statistical criteria, the study provides an empirical basis for the subsequent design guidelines and interpretation of material-form relationships.

4.1 Measurement Model: Assessment of Formative Indicators

The formative measurement model was assessed primarily through collinearity (VIF), outer weights, outer loadings, and the statistical significance of the outer weights. The VIF results indicate that most values were below the conservative threshold of 5.0, although a small number of indicators showed relatively higher values. In particular, the VIF value for T3–K2 was 5.079, indicating a borderline level of collinearity that was carefully considered in the interpretation of the formative indicators. The remaining relatively higher VIF values were also examined to ensure that collinearity did not compromise the interpretation of the formative measurement model.

The bootstrap analysis of outer weights showed that most of the selected bench morphologies (B1–B10) and textures (T1–T3) made statistically significant contributions to the respective Kansei constructs ($p < 0.05$). Where an outer weight did not reach statistical significance, the corresponding outer loading was additionally examined as a supplementary criterion for indicator retention. For example, although the outer weight of B2–K4 was not statistically significant ($p = 0.104$), its outer loading was substantial (0.817), supporting the retention of the indicator within the formative construct. Thus, indicator retention was not determined solely by the significance of the outer weight, but through a combined assessment of outer weights, outer loadings, and collinearity. The complete results of the bootstrap significance assessment are reported in Table 1.

Table 1: *Measurement Model Table.*

Physical Feature	Kansei Factor	Outer Loading	VIF	Outer Weight	*T*-Statistic	*P*-Value	Decision
B10	K1	0.850	2.334	0.307	26.242	<0.001	Retained
B10	K2	0.902	2.940	0.331	24.950	<0.001	Retained
B10	K3	0.854	2.086	0.327	25.480	<0.001	Retained
B10	K4	0.725	1.558	0.221	14.640	<0.001	Retained
B2	K3	0.832	1.363	0.503	2.699	0.007	Retained
B2	K4	0.817	2.020	0.295	1.624	**0.104**	Retained based on loading
B2	K5	0.837	1.934	0.411	3.075	0.002	Retained
B6	K1	0.876	2.323	0.363	37.629	<0.001	Retained
B6	K2	0.919	2.805	0.399	37.616	<0.001	Retained
B6	K3	0.849	1.860	0.372	33.340	<0.001	Retained
B8	K1	0.776	1.588	0.432	4.872	<0.001	Retained
B8	K2	0.749	1.681	0.266	2.281	0.023	Retained
B8	K3	0.815	1.199	0.571	4.830	<0.001	Retained
T2	K1	0.873	3.105	0.214	33.914	<0.001	Retained
T2	K2	0.910	4.073	0.237	35.237	<0.001	Retained
T2	K3	0.898	3.456	0.235	33.460	<0.001	Retained
T2	K4	0.892	3.843	0.227	33.795	<0.001	Retained
T2	K5	0.873	3.449	0.209	32.936	<0.001	Retained
T3	K1	0.847	2.919	0.227	40.955	<0.001	Retained
T3	K2	0.910	4.367	0.246	37.519	<0.001	Retained
T3	K3	0.871	2.954	0.232	40.417	<0.001	Retained
T3	K4	0.830	2.537	0.227	37.122	<0.001	Retained
T3	K5	0.855	2.769	0.226	39.202	<0.001	Retained
B10	K1	0.784	2.414	0.193	21.751	<0.001	Retained
Total Bench							
B10	K2	0.806	2.985	0.213	24.668	<0.001	Retained
B10	K3	0.797	2.254	0.212	27.456	<0.001	Retained
B6	K1	0.761	2.371	0.208	26.809	<0.001	Retained
B6	K2	0.836	3.046	0.227	29.554	<0.001	Retained
B6	K3	0.780	2.163	0.215	28.859	<0.001	Retained
T2	K2	0.771	4.303	0.151	35.488	<0.001	Retained
Total Texture							
T2	K3	0.765	3.924	0.149	29.145	<0.001	Retained
T2	K4	0.738	2.690	0.145	28.003	<0.001	Retained
T3	K1	0.799	2.966	0.162	33.732	<0.001	Retained
T3	K2	0.866	**5.079**	0.172	33.210	<0.001	Retained
T3	K3	0.818	3.257	0.161	33.384	<0.001	Retained
T3	K4	0.797	2.646	0.157	28.412	<0.001	Retained
T3	K5	0.796	2.992	0.160	34.020	<0.001	Retained

Note: The t-statistics and p-values reported in Table 1 refer to the bootstrap significance testing of the outer weights. Indicators with statistically significant outer weights ($p < 0.05$) were retained in the formative measurement model. Where an outer weight did not reach statistical significance, the corresponding outer loading was additionally examined as a supplementary criterion for indicator retention. Accordingly, an indicator with a non-significant outer weight could be retained when its outer loading provided sufficient empirical support for its contribution to the formative construct.

4.2 Structural Model and Explanatory Power

The explanatory power of the structural model was assessed using the coefficient of determination (R^2), which indicates the proportion of variance in the endogenous constructs explained by the explanatory variables. As summarized in Table 2, the R^2 values for the endogenous constructs, Total Bench and Total Texture, were 0.991 and 0.995, respectively.

According to the benchmarks proposed by Hair et al. (*2017*), R^2 values exceeding 0.67 indicate substantial explanatory power. The high values observed in this study indicate that the structural model accounts for a substantial proportion of the variance in the endogenous constructs. These results provide strong empirical support for the relationships between morphology, texture, and the Kansei dimensions examined in the model, within the context of the present study.

Table 2: *Explanatory power of the structural model* (R^2 values).

Dependent Variable	R^2	adj R^2	Explanatory Power
Total Bench	0.991	0.991	Very Strong
Total Texture	0.995	0.995	Very Strong

Discussion: The Dialectics of Stone and Soul

The transition from quantitative analysis to theoretical interpretation allows for a profound interrogation of how materiality relates to the emotional experience of urban spaces. The empirical findings of this study do not merely provide statistical correlations; they reveal meaningful relationships between the physical characteristics of stone and users' Kansei responses. By synthesizing the data through the lenses of phenomenology and architectural theory, this section explores how the "material dignity" of *Pietra Serena* may be understood within the contemporary urban experience. The results suggest that the emotional experiance of urban furniture is related not only to its form but also to the interaction of haptic and visual characteristics. This discussion is organized around three thematic axes: the perception of minimalism, the role of touch, and the relationship between material rigidity and bionic ergonomics.

5.1 The Minimalist Paradox: Less is More through Matter

The empirical evidence reveals a compelling alignment between minimalist sensibilities and structural morphology. Specifically, the substantial association (0.803) observed between the Minimalist factor (K3) and Structural-Geometric morphology (B8) underscores the role of *Pietra Serena* as a tactile vehicle for "Self-sufficiency." This concept, central to the discourse of traditional Iranian architecture *(Pirnia, 2008)*, finds a contemporary parallel in the functionalist ethos of Mies van der Rohe *(Blaser, 1986)*, where the essence of the object is stripped of additive ornamentation to reveal its core truth.

The findings suggest that in the urban fabric, the perceived value of the object is derived from the material's authenticity rather than decorative complexity. By leveraging geometric clarity (B8), the intrinsic chromatic qualities and dignified presence of *Pietra Serena* are amplified, transforming a functional urban utility into a minimalist monument. This result supports the hypothesis that geometric reductionism, when paired with a material of high ontological value, does not result in emptiness, but rather in a dense serenity that embodies both structural rigor and aesthetic transcendence.

5.2 Haptic Authenticity: The Triumph of the Flamed Texture

A pivotal finding of this research is the predominance of the Flamed Texture (T3) in sculpting the construct of Authenticity construct, with an outer weight of 0.659. This empirical result resonates with the ontological interrogation of how architecture facilitates dwelling and uncovers the essence of a site *(Heidegger, 1971)*. While polished surfaces (T1) often act as a sterile, specular barrier that obscures the stone's intrinsic materiality, the flamed treatment foregrounds the natural grain and mica particles, effectively actualizing Merleau-Ponty's *(2002)* primacy of perception.

This creates a visceral tactile dialogue, where the observer's body interacts directly with the material medium, bypassing the cognitive filter. Consequently, the findings imply that sensory roughness is perceived not as a flaw, but as a manifestation of temporal depth. The findings therefore suggest that materials evoking an ancestral or natural antiquity through haptic engagement may contribute among urban observers. This suggests that for urban furniture to evoke trust and permanence, the design must prioritize textures that celebrate the raw, unadulterated nature of the stone. This alignment between tactile roughness and perceived authenticity is further supported by recent research indicating that the materiality of street furniture significantly modulates the emotional state and atmospheric perception of pedestrians *(Lee & Kim, 2021)*.

5.3 Bionic Ergonomics: Resolving the Hardness of Stone

The empirical results underscore a synergistic relationship between Bionic-Organic morphologies (B6, B10) and Bush-hammered textures (T2) in optimizing Ergonomic (K4) and Safety (K5) perceptions. This synthesis unveils a profound dialectic: the perceived coldness and rigidity of stone are moderated by organic curves that mimic human anatomy, potentially reducing the psychological friction between the user and the material *(Ishikawa & Nishikawa, 2026)*.

The structural model suggests a Gestalt-like perception of security, indicating that perceived safety in urban furniture may involve not only the absence of hazardous edges but also the perceived tactile characteristics of the surface. This is supported by the relatively higher weight of the T2 texture compared with the B10 form, suggesting that tactile friction may contribute to perceived safety. In this context, the perceived reliability of the material surface appears to have a stronger influence than geometric form within the present model. This finding provides a potential design guideline for manufacturers: to soften the perceived hardness of stone, designers may consider integrating bionic geometries with controlled surface roughness, thereby creating a more welcoming and ergonomic urban furniture experience.

Kansei-Based Design Framework

To translate the empirical findings into a practical application for urban designers, a Kansei-based design framework has been developed. The framework bridges the statistical results and the design process by translating the outer weights of the structural model into a structured tool for interpreting material and formal relationships. By operationalizing these estimated weights, the framework provides a systematic means of relating specific material and morphological characteristics to the Kansei dimensions identified in the study. This approach can support designers in evaluating material-form combinations and making informed design decisions within the context of *Pietra Serena* urban furniture.

6.1 The Final Explanatory Model: A Kansei Framework for Form and Texture

As depicted in Figure 3, the final explanatory model serves as a cognitive bridge, translating abstract statistical weights into an actionable visual design framework. By substituting alphanumeric codes with representative visual imagery, the model facilitates a seamless transition from empirical evidence to tangible design implementation. The robustness of this framework is underscored by the exceptional explanatory power of the model, with R^2 values of 0.991 for Total Bench and 0.995 for Total Texture, indicating that a substantial proportion of the variance between the observed physical variables in these endogenous constructs is explained by the model. The observed variations in the affective perceptions of *Pietra Serena* suggest that Kansei responses are influenced by individual experience, aligning with the findings of Lee and Stappers *(2002)*, who demonstrated that experience profoundly alters the cognitive mapping of emotional attributes.

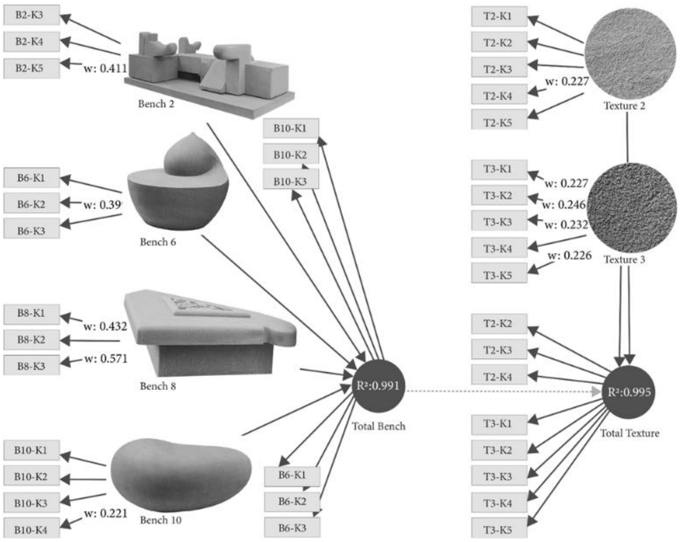

Figure 3: *The Final Explanatory Model: A Kansei-Based Framework for Users' Haptic Responses to Stone Bench Form and Texture.*

6.2 Selection and Interpretation of the Primary Design Drivers

The structural model was first used to identify and examine the relationships between the material-form characteristics and the five Kansei constructs. In this stage, the path coefficients represented the estimated relationships within the structural model and served to determine the relevant paths between the design variables and Kansei responses. Based on the resulting model, all five Kansei constructs were retained as relevant components of the final Kansei-based design framework. Following the identification of these relationships, the outer weights obtained from the formative measurement model were used to formulate the design equations for each Kansei construct. Rather than using the path coefficients to construct the equations, the outer weights were employed to represent the relative contribution of the retained material-form variables within each Kansei response. This distinction allows the structural model to serve its intended role in identifying the relevant relationships, while the measurement-model results provide the quantitative basis for combining the corresponding design variables into the final equations.

The resulting equations therefore provide a systematic representation of the relationships identified through the structural model while translating the relevant measurement-model weights into a design-oriented formulation. They enable the interpretation and comparison of different combinations of form and texture characteristics in relation to the five Kansei responses associated with *Pietra Serena* urban furniture. To maintain clarity and avoid unnecessary complexity, the final design formulation focuses on the variables that demonstrated stronger observed relationships within the established model. It provides a more streamlined representation of the variables that were most relevant within the present analysis and facilitates their practical interpretation in the design context.

6.3 Kansei-Based Design Formulation

Based on the retained outer weights obtained from the PLS-SEM analysis, a set of Kansei-Based Design Recipes was developed to translate the statistically identified relationships into practical design combinations. These formulations are intended as a design-oriented representation of the relative contribution of selected bench-form and texture characteristics to each Kansei factor.

The coefficients in the following formulations are outer weights, indicating the relative contribution of each design characteristic to the corresponding Kansei construct. They are not correlation coefficients, regression coefficients, or interaction effects. Accordingly, the resulting total scores are derived aggregate contribution scores, calculated by summing the retained outer weights for the selected form–texture combination. They should therefore be interpreted as comparative design indicators within the present model, rather than as direct Kansei scores or measures of model accuracy.

The resulting design recipes are as follows:

1. Authenticity (K1)

$K1=(0.432\times B8) + (0.227\times T3)$

Total K1 = 0.659

Strategic Pairing: Structural-Geometric form + Flamed texture

This combination identifies B8 and T3 as the retained design characteristics with the highest combined contribution to the Authenticity construct within the final model.

2. Aesthetics (K2)

$K2=(0.399\times B6) + (0.246\times T3)$

Total K2 = 0.645

Strategic Pairing: B6 + Flamed texture

This formulation identifies the B6 form characteristic and T3 texture as the selected combination contributing most strongly to the Aesthetics construct according to their retained outer weights.

3. Minimalism (K3)

$K3=(0.571\times B8) + (0.232\times T3)$

Total K3 = 0.803

Strategic Pairing: Structural-Geometric form + Flamed texture

The value 0.803 represents the combined contribution of B8 and T3 to the Minimalism construct, calculated as 0.571+0.232. It is therefore a derived aggregate contribution score, not a correlation coefficient and not a statistical test of synergy or interaction.

4. Ergonomic Comfort (K4)

$K4=(0.221\times B10) + (0.227\times T2)$

Total K4 = 0.448

Strategic Pairing: Bionic-Organic form + Bush-hammered texture

This combination represents the selected form–texture pairing with the highest combined retained contribution to the Ergonomic Comfort construct.

5. Safety/Hygiene (K5)

$K5=(0.411\times B2) + (0.226\times T3)$

Total K5 = 0.637

Strategic Pairing: B2 + Flamed texture

This formulation identifies B2 and T3 as the selected design characteristics contributing to the Safety/Hygiene construct according to their respective outer weights.

Interpretation of the Design Recipes:

Taken together, these five formulations translate the statistical results into a concise design decision structure. Each recipe identifies the form and texture characteristics that make the largest retained contributions to a specific Kansei dimension. The formulations therefore provide a bridge between the quantitative Kansei analysis and practical design application.

Importantly, these equations should not be interpreted as conventional explanatory equations. The coefficients are derived from the outer weights of the measurement model, while the total values represent the combined contribution of the selected characteristics. Similarly, the pairing of a form and a texture does not constitute a formally tested Form × Texture interaction or statistical synergy. Rather, it represents a data-derived strategic design combination identified through the Kansei matrix and the final PLS-SEM model. Accordingly, the five Design Recipes provide a structured method for translating users' Kansei evaluations into design-oriented form–texture recommendations while maintaining a clear distinction between statistical measurement results and their subsequent design interpretation.

Conclusion and Practical Implications

This research establishes a synthesis between the artisanal legacy of Renaissance craftsmanship and the systematic approach of contemporary Kansei Engineering. By examining the haptic and visual qualities of *Pietra Serena* urban furniture, the study translates subjective perceptions of material and form into measurable Kansei responses and investigates their relationships with selected material and morphological characteristics through a structured modelling approach. The resulting framework provides an empirically grounded basis for understanding how specific design characteristics are associated with users' emotional perceptions and for supporting more informed material-form decisions in urban furniture design.

Rather than treating material perception solely as a matter of aesthetic intuition, the study demonstrates how users' emotional responses can be investigated through a structured measurement and modelling process and translated into evidence-based design decisions. The findings therefore contribute to the intersection of material perception, cultural heritage, and urban furniture design.

7.1 Theoretical Contributions

The primary theoretical contribution of this study is the formalization of material and form perception through a structured Kansei Engineering-based framework. The approach moves beyond purely intuitive interpretations by operationalizing users' perceptions through measurable Kansei dimensions and examining their relationships with selected characteristics of *Pietra Serena* urban furniture.

The structural modelling process enables the identification of the relationships that remain meaningful after refinement of the initial set of indicators. By focusing on the retained relationships rather than incorporating every measured characteristic into the final model, the study provides a more focused representation of the associations between material-form characteristics and Kansei responses. This refinement also reduces unnecessary complexity and information redundancy, facilitating clearer interpretation and practical application of the findings.

The study therefore contributes to a more systematic understanding of how selected material and morphological characteristics can be associated with users' perceptions in the context of urban furniture. Although the empirical investigation focuses specifically on *Pietra Serena*, the methodological procedure may provide a basis for investigating other materials and cultural contexts, provided that the relationships are re-examined and empirically validated in each new application.

7.2 Managerial and Industrial Implications

Beyond its theoretical contribution, this research offers practical implications for urban designers, municipal planning authorities, and urban furniture manufacturers. The proposed Kansei-based framework can support material-form decisions by connecting selected design characteristics with users'observed emotional responses. For municipal authorities and urban planners, the findings provide an evidence-based reference for the design and selection of *Pietra Serena* urban furniture. Rather than relying exclusively on conventional aesthetic judgement, designers can consider the relationships identified by the structural model when developing material-form combinations intended to evoke particular Kansei responses. This approach enables material characteristics, morphology, cultural identity, and user perception to be considered together in the design process.

For the stone and manufacturing industries, the findings suggest the potential value of considering stone not only as a physical resource but also as a perceptual and cultural design medium. The identified material-form relationships may inform the development of digitally fabricated or CNC-machined stone components when the resulting forms correspond to the characteristics examined in the study. However, technical feasibility, production costs, structural requirements, and manufacturing constraints must be evaluated independently and were beyond the scope of the present research. The proposed framework should therefore be understood as a design decision-support approach rather than a universal or prescriptive design formula. Its practical value lies in translating empirical evidence about users' perceptions into more focused and conscious material-form decisions while avoiding unnecessary complexity in the design process.

7.3 Final Thought

Transcending the cold precision of statistical fit and the rigorous weights of Hair et al. *(2017)*, the design of urban furniture with *Pietra Serena* reveals itself as a profound act of sculpting meaning from the inertia of matter. In this pursuit, the Kansei approach, grounded in Nagamachi's methodology *(1995)*, operates as a modern chisel, extracting the latent essence of form from the depths of material. This process resonates with Michelangelo's timeless conviction that the figure is already present within the stone, awaiting only the removal of the redundant to be set free *(Schulz, 1975)*.

Within this framework, *Pietra Serena* is redefined: it is no longer a mere geological substrate, but a strategic cultural medium. The structural model serves as the operational mechanism that aligns human emotional perception with the intrinsic properties of the material. By integrating the aesthetic proportions of the Renaissance with the rigor of contemporary minimalism, this framework transcends its primary application. It establishes a generalizable methodology for identifying and extracting the latent potentials of diverse mineral resources, ultimately fostering a profound sense of place and ensuring a sustainable, emotionally resonant urban future**.**

Relevance to Design Practice: Consequently, the findings of this research offer a critical, evidence-based guide for municipal urban planning authorities and urban furniture manufacturers, facilitating an optimized and conscious selection of materials that balances industrial viability with cultural and aesthetic excellence in public space design.

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