Original Article
ISSN (Online): 2582-7472

ShodhKosh: Journal of Visual and Performing Arts
Special Issue on AI-Driven Creativity and Intelligent Practices in Visual Arts 2025 6(4s)

DATA VISUALIZATION AS A FORM OF SCULPTURAL ART

Manivannan Karunakaran [1], Praney Madan [2], Sachin Pratap Singh [3], Peeyush Kumar Gupta [4], Mohd Faisal [5], Fazil Hasan [6], Mahesh Kurulekar [7]

[1] Professor and Head, Department of Information Science and Engineering, JAIN (Deemed-to-be University), Bengaluru, Karnataka, India
[2] Centre of Research Impact and Outcome, Chitkara University, Rajpura- 140417, Punjab, India
[3] Assistant Professor, Department of Journalism and Mass Communication, Vivekananda Global University, Jaipur, India
[4] Assistant Professor, ISDI - School of Design and Innovation, ATLAS SkillTech University, Mumbai, Maharashtra, India
[5] Lloyd Law College, Greater Noida, Uttar Pradesh 201306, India
[6] Associate Professor, School of Business Management, Noida International University, India
[7] Department of Civil Engineering Vishwakarma Institute of Technology, Pune, Maharashtra, 411037, India

Received 18 April 2025
Accepted 24 August 2025
Published 25 December 2025

Corresponding Author
Manivannan Karunakaran,
manivannan.k@jainuniversity.ac.in

DOI
10.29121/shodhkosh.v6.i4s.2025.6863

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

ABSTRACT

Data visualization, the interconnection of information and sculptural art is a new paradigm where information moves out of the digital screens and finds space in the physical world to express itself. This paper examines the conceptual, aesthetic and technological systems that allow the data to be physically realized as three dimensional artworks. It investigates how datasets are transformed algorithmically and modeled computationally into forms that provoke sensory, emotional and intellectual interaction. The paper contextualizes the current practices in the context of the historical path of abstract visualization and data physicalization to identify the connection of the modern practice with the information design and artistic tradition. The research methodologically describes the following processes: the choice of the dataset, semantic-geometric mapping, application of digital fabrication tools, including 3D printing, CNC, and laser cutting. Machine learning adds value to the technological ecosystem by supporting pattern extraction, generative modeling through Grasshopper and Houdini, and previews of the sculpture in real-time. The aesthetic inquiry is concerned with the ability of the physicalized information to tell visual tales, mediate perception, balance between science and creative interpretation. It is further discussed with regards to issues of material constraints, sustainability and representation of multidimensional datasets. This study, finally, makes the data-driven sculpture be both an art and an epistemological practice, i.e. the way of turning data into an embodied and spatial conversation of information, materiality and human experience.

Keywords: Data Physicalization, Generative Design, Computational Sculpture, Aesthetic Information Mapping, Digital Fabrication

1. INTRODUCTION

Data visualization has taken the form of the interface between creative expression and analytical thinking in the changing world of art, design and information science. Visualization has traditionally been focused on the two-dimensional charts, infographics and dashboards and helped to make sense of complex data by converting numerical or categorical data into visual patterns that can be observed. Nevertheless, with the emergence of new computational technologies, generative modeling, and the physicalization of data, this area has now gone beyond the flat screen- it is now physically represented as data physicalization or sculptural visualization. This change does not just imply a shift in medium but paradigmatic shift in the way in which data may be perceived, understood and embodied. The process of transforming abstract data into three-dimensional sculptural constructions changes the interaction between the object, information, and the viewer, establishing novel perception, emotion, and interaction possibilities. The concept of data as matter is consistent with the wider art trends that mislead the boarders between science and aesthetics Nisiotis et al. (2020). According to the same logic as the traditional sculpture, where imagination and physicality are transformed into form, the data-driven sculpture combines algorithmic logic with artistic intent, bringing thoughtless phenomena into the real world, as the material interactive sculpture. An example would be the metrics of climate change in the form of undulating topographies; the feelings of the social media in the form of pulsating organic forms; and the sound frequencies represented by a complex lattice. These representations disrupt the traditional definition of art and analytics since it no longer revolves around accuracy but rather expressive embodiment, the place where the meaning is created through the combination of information, design and physical environment Monaco et al. (2022).

Gradually, with the democratization of computation, as made available through software such as Processing, Rhino-Grasshopper and TouchDesigner, artists and designers developed a new mode of engagement through information, as both input and co-creator in the generative process. This development is a major point of convergence of art and technology - making datasets sculptural grammars that can be created, displayed, and touched in the physical world. Regarding the perception, sculptural data visualization allows the experience of a multi-sensory perception. Physical forms, unlike the visualizations on the screen, touch, spatial orientation and emotional resonance are all used Bekele et al. (2018). This was a dimension of touch that helps to create a deeper sense of connection with the audience and makes the audience curious and reflective. It makes information interpretation more democratic, as any human being, not only specialists, is able to explore information physically, understand patterns and feel the connection. Figure 1 demonstrates multistage framework on the basis of which data is converted into expressive visualizations in sculptural form. Additionally, these physical experiences have the ability to cross over linguistic and cognitive boundaries so that complex data could speak conceptually using space and material representation.

Figure 1

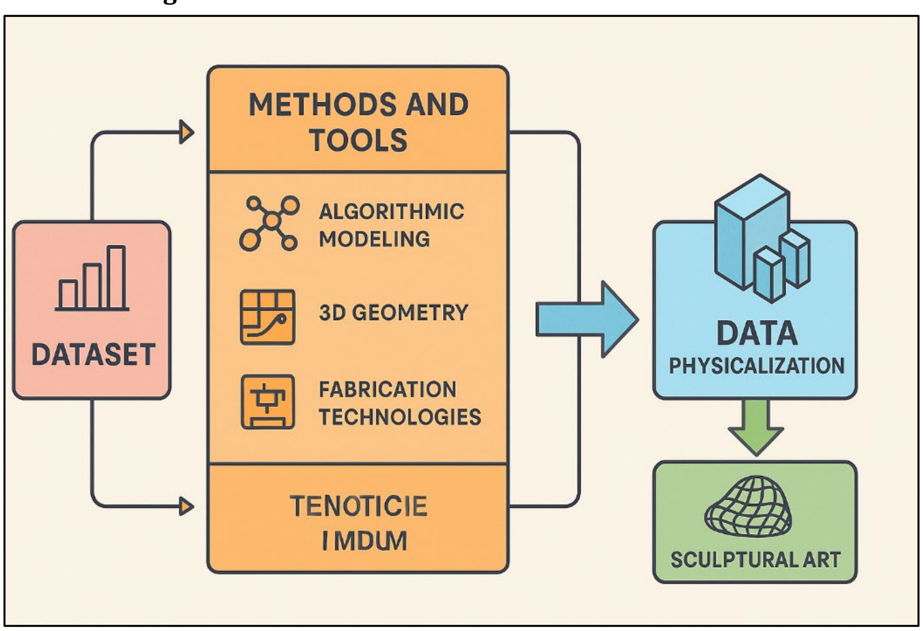

Figure 1 Multistage Framework of Data Visualization as Sculptural Art

This new form of art provides a merging of data analytics, machine learning, and generative design that is technologically exploited. Parametric and algorithmic design tools transform the patterns found in datasets into morphologies that can be fabricated, whereas machine learning models reveal the latent patterns found in the datasets. In terms of digital models, 3D printing, CNC milling and laser cutting, techniques bring digital models into contact with material reality, and translation of pixels into physicality, in other words, is smooth Maiwald et al. (2021). Such sculptural works are frequently supplemented with interactive and kinetic, in which the sculpture is sensitive to real-time data feeds, and thus represents a story in flux.

2. THEORETICAL FOUNDATIONS

2.1. DEFINITIONS OF DATA VISUALIZATION, PHYSICALIZATION, AND SCULPTURAL INTERPRETATION

Data visualization is the art of interpreting either numerical or categorical data in visual ways that can be used to identify patterns, generate insights as well as communicate. It is a cognitive interface between the complexity of information and human perception in that abstract datasets can be perceived in the form of color, geometry and space. However, data physicalization takes this process one step further into the physical world, where data is instantiated in the form of physical, and often three dimensional, objects Rahaman et al. (2019). These objects may be passive or interactive and the users are invited to engage with information by touching it, moving it, and navigating a space. Physicalization makes visualization physical, so that information which is abstract and intangible is actualized in three-dimensional sculpture that blends informational logic with aesthetic purpose Arrighi et al. (2021).

2.2. HISTORICAL EVOLUTION FROM SYMBOLIC ABSTRACTION TO TANGIBLE FORMS

The evolution of the symbolical abstraction into the physical data representation is both the indicator of the technological progress and the alterations of the thought of the art. The origins of visualization that include the statistical charts developed by William Playfair in the 18th century may be regarded as the foundation of the symbolic form of abstraction since both of them attempted to reach the clarity through the use of geometric simplicity. As the speed of computing increased in the 20th century, information visualization started to take center stage in the scientific exploration in the shape of digital graphs, network maps, and algorithmic renderings that reduced the complexity to abstract visual syntax Ceccotti (2022). With this also came a new generation of cybernetic and information aesthetics, including Max Bense and Herbert Franke, which began to conceptualize in terms of information as an art material, and to emphasize the aesthetic constituent of information. Experimental intersections were pursued in the 1960s and 1970s by artists such as Vera Molnar and Frieder Nake and Edward Ihnatowicz to make geometric compositions and robotic sculptures. These researches marked the transition to the data-driven art concept to combine the rational programming with the sensory representation Rauschnabel et al. (2022). Later 20th and early 21st centuries gave such conceptualizations digital construction, and parametric modeling and made the data physically manifest itself in sculptural forms possible.

2.3. CONCEPTUAL FRAMEWORKS LINKING AESTHETICS, PERCEPTION, AND INFORMATION DESIGN

Theoretical models of the relationships between aesthetics, perception, and information design explain human cognition in information-processing modes other than the analytical-cognitive one sensory and emotional cognition. The Gestalt-based perception theory postulates that people desire to achieve coherence and pattern recognition in visual forms. When this principle is applied to the data visualization and physicalization, aesthetic harmony, balance, and rhythm help to understand. Aesthetics, in turn, does not serve as ornamentation but as an epistemological instrument which contributes to more understanding and emotional appeal Theodoropoulos and Antoniou (2022). In information design, aesthetics is the facet between disclosure and involvement. Perceptual affordances are directed toward attention and meaning-making by the material, color and spatial organization. Intentionality Artistic intentionality adds to this model: visualizations in sculpture goes beyond a description of data to include interpretive stories that arouse the imagination and thought. Table 1 summarizes related works in terms of the methods, use of data, contribution and limitation. Fusing semiotics, the study of signs and meaning, with computational design, such works convey in both quantitative and qualitative truth, the quantitative truth of information and the qualitative truth of composition.

Table 1

Table 1 Comparative Overview of Related Works in Data-Driven Sculptural Visualization

Project Title	Data Type Used	Technique	Material or Medium	Impact
Artistic Data Sculptures for Social Visualization	Social Media Text Data	Aggregated Pattern Mapping	Acrylic Layers	Enhanced audience empathy via transparency and layering
Opportunities and Challenges for Data Physicalization	Multivariate Data	Data-to-Form Encoding Framework	Mixed Materials	Defined taxonomy for physicalization approaches
Exploring Tangible Data Representations	Quantitative and Qualitative Data	Tangible Interaction Models	3D Printed Objects	Highlighted tactile engagement benefits
Data by Proxy: Material Traces and Quantified Reality Lo Turco et al. (2022)	Urban Environmental Data	Trace-Based Physical Mapping	Metal & Concrete	Connected environmental sensing with artistic form
Data Physicalization: From Visual to Tangible Willkens et al. (2020)	Scientific Data	Algorithmic Mapping to Geometry	PLA / Resin	Promoted hybrid data interpretation frameworks
Affective Data Sculptures: Emotive Quantification	Biometric / Emotional Data	Generative Emotion Mapping	3D Printed Resin	Demonstrated emotional connection via physical data
Critical Info-Aesthetics Pourmoradian et al. (2021)	Cultural & Textual Data	Conceptual Visualization	Paper / Wood	Encouraged critical interpretation over utility
Tangible Topographies of Data	Geospatial / Climate Data	Topographic Height Mapping	CNC Wood Panels	Enhanced geographic cognition through tactile surfaces
Algorithmic Art and Information Aesthetics El-Said and Aziz (2022)	Mathematical Structures	Algorithmic Plotting	Ink / Plotter	Inspired digital-to-physical generative art lineage
Embodied Data Narratives in Installation Art	Behavioral Data	Generative Spatial Composition	Metal Frames + Light	Fostered immersive environmental storytelling

3. DATA PHYSICALIZATION AND SCULPTURAL EXPRESSION

3.1. PRINCIPLES OF TRANSFORMING DATASETS INTO THREE-DIMENSIONAL STRUCTURES

Convergence of data science, computational geometry and aesthetic design is the key to transformation of datasets into three dimensional structures. The basic principle is to map the abstract variables on spatial dimensions whereby the numerical or categorical data defines the data parameters like the shape, scale, curvature, texture, or density. That process turns the raw data into an embodied spatial narrative that allows perceiving patterns in terms of volume and proportion Luther et al. (2023). The overall shapes are not literal copies of information but beautiful representations which strike a balance between accuracy and expressionism. Also, the symmetry aspect, rhythm and structural stasis play a role in the final result, making sure that the sculpture has artistic unity, as well as, material viability.

3.2. MATERIALITY AND FORM: WOOD, METAL, ACRYLIC, DIGITAL FABRICATION

Materiality is very important in defining how the data-driven sculptures convey meaning, emotion, and the sense of touch. The decision of material, whether it is a wood, metal, acrylic or hybrid composites is not only an aesthetic but a conceptual decision, between the physical and informational dimension of the piece of art Pisoni et al. (2021).

Wood is cozy, organic, and man-made, and is typically appropriate in the depiction of ecological or chronological data. Figure 2 indicates the combination of materiality and form to make data-driven sculptural objects. Its texture and grain bring in a natural irregularity to counter anything that is algorithmic and focus on the discussion between nature and data. Metal, as a material that is rigid and reflective, is an icon of strength, modernity and permanence. Industrial or infrastructural data can be represented as stainless steel or aluminum, whereas more complex inscriptions of data can be made on surfaces, such as anodizing or laser etching. The transparency of acrylic and other translucent materials is used as a metaphor of clarity, flow and immateriality, which is best suited to represent light-based or fluid datasets. These materials are dynamically receptive to lights and cast changing patterns and shadows, which bring the data experience out into environmental space.

Figure 2

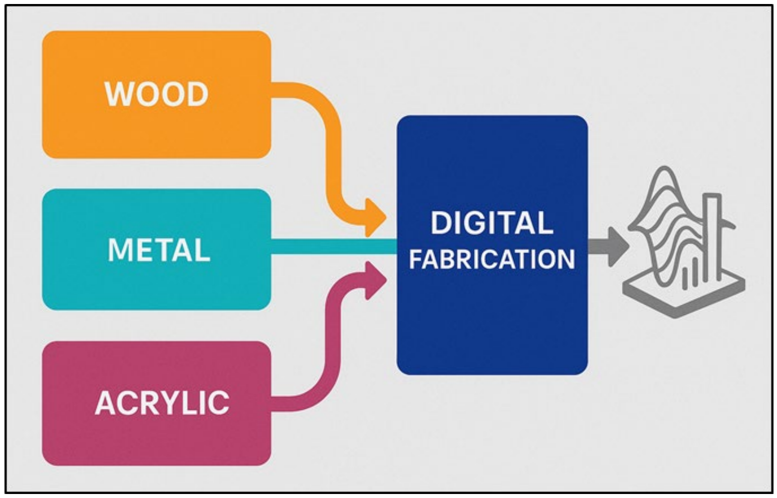

Figure 2 Materiality and Form Integration in Data-Sculptural Fabrication

3.3. SPATIAL COMPOSITION, EMBODIMENT, AND VIEWER INTERACTION

In data-based sculpture, spatial composition characterizes the positioning and relations of information concerning physical and perceptual space. In contrast to the conventional visualization where meaning is limited to a frame or a screen, data sculpture as a spatial experience is a three-dimensional experience. The composition is a coordination of scale, direction, rhythm, to define the way the viewer perceives and manages the form. Designers apply rules of equilibrium, repetition and contrast to scale data relationships into choreography of volume- where every curve, gap or density contains a certain pattern of information. Embodiment introduces an additional performative aspect, which places the data as well as the viewer into a common space of dialogue. With the viewer walking about the sculpture, there is a change in perspective as new correlations and hierarchies become evident and thus observation becomes interpretation. The interactive technologies like sensors, LEDs, or kinetic mechanisms are incorporated in some works and react to real-time streams of data or the nearness of the audience.

4. METHODS AND DESIGN PROCESS

4.1. DATASET SELECTION AND SEMANTIC MAPPING TO 3D GEOMETRY

The making of data-driven sculptures starts with the strategic selection of the dataset, thus defining the conceptual purpose as well as the logic of the structure behind the final form. The selected data set should be semantically rich - it needs to have a story or a thematic meaning which qualifies its translation into a physical form. As an example, the climate records, or population movements or emotional sentiment data each have visual languages that are distinctly dissimilar when turned into geometry. One should not reproduce the data word-to-word but rather distill the expressive properties of the data to find the variables that can be expressed by the means of shape, volume, and material. After curating and cleaning the data, the next stage is called semantic mapping and it involves matching data variables with the associated geometric parameters. Spatial elements like height, curvature or density are associated with quantitative aspects like frequency, magnitude or correlation. Colors, textures or modular arrangements can be defined by categoricals. Such mapping creates a visual grammar, which allows data relationships to appear in the three-dimensional structure.

4.2. ALGORITHMIC MODELING AND COMPUTATIONAL DESIGN TECHNIQUES

Data-sculptural design consists of algorithmic modeling as its creative and technical backbone, that is, semantic mappings are transformed into actual geometries by rule-based computation. Algorithms in this stage are generative systems that perceive the information input to create complex forms that cannot be created manually. Parametric and procedural modeling Designers utilize parametric and procedural modeling tools such as Rhino -Grasshopper, Houdini, and Processing to define the relationships between the data parameters and geometric changes. The constraints, iterations, and dependencies are encoded by each algorithm resulting in a structure that is living and changes depending on variations in the dataset. There are technologies like lofting, mesh subdivision, Voronoi tessellation and point-cloud reconstruction to form organic and not a priori complex surfaces and spatial patterns out of data-driven logic. Machine learning models can additionally be applied in generative design processes to discover latent models or to optimize aesthetic settings. The precision and serendipity created by these computational systems allow designers to improvise a space of design by searching vast and algorithmically created designs.

4.3. INTEGRATION OF FABRICATION TECHNOLOGIES

4.3.1. 3D PRINTING

With the use of 3D printing, it is possible to transform digital models to tangible data sculptures with its high accuracy and geometric complexity. Additive manufacturing is used to fabricate forms of an algorithmic nature by layering material, usually resin, PLA or metal powder, sequentially to build up the desired shape. The method is most suited to the manufacture of convoluted lattices or organic encodings of geometries and volumetric data that would not have been possible in a manual fabrication procedure. 3D printing can also be used to print multi-material and color data such that categorical or scalar information can be represented directly in the texture or colour of the structure. Its easy approach, and also scalability are handy in the exploration of prototypes, as well as in end sculptural installations. Of significance, 3D printing offers a links data abstraction and physical representation to offer material mode of computation in which computational aesthetics are brought to life. The printed edition is a digital piece of digital intelligence - all the layers are parts of material documentation of an algorithmic process, that is, it unites information science, accuracy of the engineering and art intent into a material representation.

4.3.2. CNC

CNC machines cut substances- be it wood, metal or foam using information created geometries in order to disclose spatial structures which possess informational significance. The CNC material reduction process compared to an additive technique is concentrated on articulation of surfaces, depth and tactile grain - interaction of mechanical precision and natural flaw. Parametric toolpaths of designers are designed using data driven algorithms, in which every cut is dependent on a variable in a dataset or a spatial relationship. CNC machining is especially most suitable in large or permanent installations, where physical robustness and textual articulateness is needed. It allows intricate contouring, multi-axis carving as well as hybrid assembly with other fabrication techniques. CNC will, therefore, be a translator and sculptor, bringing computational form to the physical through very fine control of motion, transposing digital patterns into physical forms which combine the rigorousness of engineering practice with the expressiveness of sculptural art.

4.3.3. LASER CUTTING

Laser cutting offers a quick and precise procedure of making planar or modular parts of data sculptures. With a focused beam of laser, acrylic, wood, or metal sheets are cut, etched or engraved accurately following algorithmic patterns based on datasets. The method is skilled at creating stratified, interlocking or grid-based visualizations regarding two-dimensional information associations where physical assemblage is recast as a information association. Laser cutting is commonly used in design by designers in data stratification, in which every layer corresponds to a time, category, or statistical dimension. These layers create volumetric illusions- when stacked or suspended, the data of light, shadow, and translucency are converted into a spatial composition, a flat data.

5. TECHNOLOGICAL ECOSYSTEM

5.1. ROLE OF DATA ANALYTICS, MACHINE LEARNING, AND PATTERN EXTRACTION

Scientific data transformation Raw data is converted into structured understanding informative of aesthetic form by using data analytics and machine learning, which are the main focus of sculptural data visualization. Precision, relevance and context are guaranteed with the help of data analytics, and unprocessed numbers can be transformed to the form of understandable variables that can be coded spatially. Patterns are formed as a result of descriptive, predictive and exploratory analysis that forms the conceptual blue print of physical manifestation. Some of the hidden structures of big or complex data sets are revealed or uncovered using machine learning like clustering, regression and dimensionality reduction algorithms. Examples are the principal component analysis (PCA) or t-SNE to cluster high-dimensional data in useful visual axes which can be then overlaid on geometric features, like curvature, volume or symmetry. The idea of neural networks and generative models are also included in the list of creative variability, and the data may evolve to these expressive forms, that is, combining the accuracy and unpredictability.

5.2. PARAMETRIC AND GENERATIVE DESIGN TOOLS

The creative center of data-sculptural processes is made of parametric and generative design tools which allow designers to convert datasets into dynamic and adaptable geometries. Programs like Grasshopper to Rhino, Processing, and Houdini offer an algorithmic environment where form is created through given relationships, and not fixed size. In parametric modeling, each structural element, whether curve, point, or surface will have adjustable parameters that are associated with data values. This enables the real time manipulation and the iterative refinement of the design, to make sure that the evolution of design is as variably represented as the dataset it is based on. Grasshopper is exceptional in the field of spatial logic and architectural structuring and allows designers to create direct data-geometry pipelines. Processing is a visual programming language that is used to create interactive and generative graphics, which is best suited to exploratory modeling or visual pattern prototyping. Figure 3 demonstrates that adaptive data-sculptural models are influenced by parametric and generative design tools. The procedural node based system of Houdini is able to support complex simulations, particle systems and volumetric modeling where data can be used to create organic and fluid morphology.

Figure 3

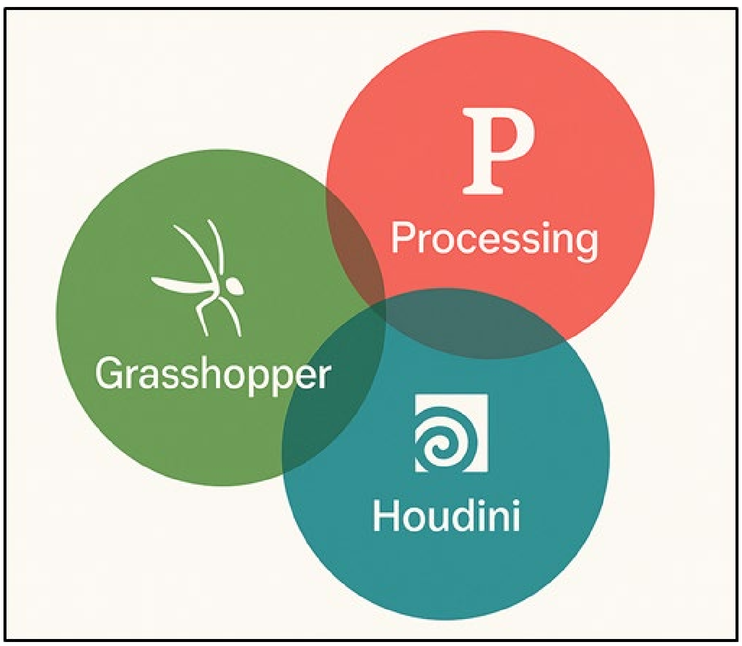

Figure 3 Parametric and Generative Design Tools in Data-Sculptural Modeling

Collectively, these technologies bring about generative authorship in which designers are in between algorithmic intelligence and aesthetic judgment. The process of work turns into a cyclical process - data is the source of form, form is the source of reinterpretation, and computation changes itself in response to the former. Coupling logic and spontaneity, the parametric and generative tools are able to make the design process an alive system of emergence, able to create sculptures that are mathematically consistent as well as artistically suggestive, that is to say, in the rhythm of the data in a form of spatial motion.

6. AESTHETIC AND INTERPRETIVE DIMENSIONS

6.1. VISUAL STORYTELLING THROUGH PHYSICAL FORM

In data sculpture, visual narrative is performed by bringing abstract information to form, texture and space. As compared to traditional narratives, which depend on text or image, sculptural storytelling relies on the spatial rhythm, proportion, and touch to convey some meaning. Every curve, every hollow, or every line turns into a piece of story, a coded bit of information, which, when combined together, turns into a story of change, association, or creation. The grouping of elements, gradients and densities reflect the relationships of time or rank among sets of data, and convert numerical acts into gestures of symbols. This type of narration survives on metaphor. The statue of the variation in climate could be waving like a tide, and the statue of the social networks could be a tree that could be fractured into some branches. These kinds of symbolism enable information to be not only understood but also evoked, so that the viewer can experience patterns, but not read them. The material decisions, to use clear acrylics or oxidized metals add to the reverberation of the narration, and indicate the data themes such as transparency, corrosion, or flux. Composition, light and perspective of the sculpture make it an experiential field of narrative involving audiences in the interpretive participation. As the viewers navigate through it, new alignments and visual relationships are created and the information that was stagnant is dynamic as stories are told. Accordingly, the sculptural system becomes a multimodal narrative tool as data analysis is turned into poetic embodiment, and information begins to speak the universal language of space and sensual perception.

6.2. COGNITIVE AND EMOTIONAL IMPACT ON AUDIENCES

The emotional and mental effect of the data sculptures is determined by the possibility to merge logical understanding and experience. Contrary to the visualizations found on screens, which favor analytical vividness, physical data representations entail incorporating more than just one of the perceptual senses: sight, touch, movement, scale, etc., forming a bodily experience with information. This multi-sensory interaction enables embodied cognition so that data are processed in a spatial and intuitively, not abstractly, way by the viewers. As seen in Figure 4, there is a framework of connection of cognitive and emotional influences in data-sculptural artworks. The brain perceives proportion, rhythm, and balance as some kind of innate stimulus and transforms statistical relations into experiences.

Figure 4

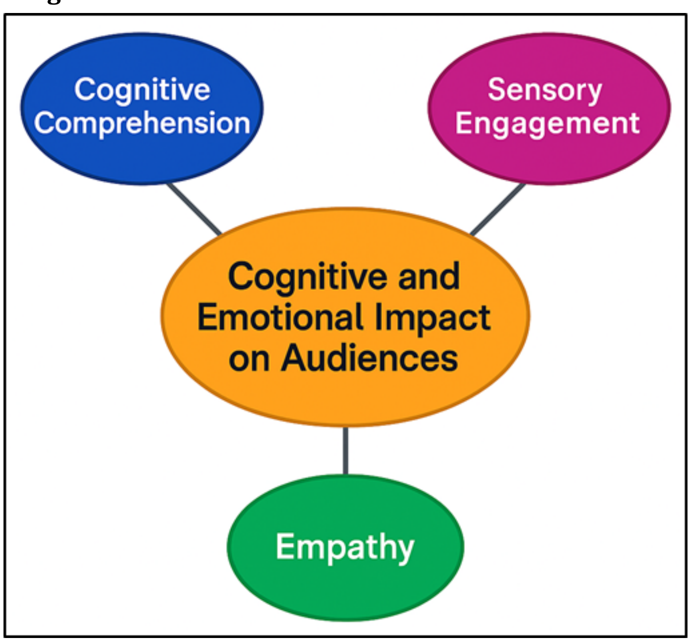

Figure 4 Cognitive and Emotional Impact Framework in Data-Sculptural Art

Sculptural visualizations have the emotional power to convert unemotional information into emotional existence. A curvy and wavy surface can be an expression of growth or peacefulness; the rough, disorganized shapes can be an expression of war or violence. This emotional appeal is based on aesthetic empathy, the ability of human beings to project sensation into perceived forms. The sculpture causes a feeling of connectivity and relation by placing the viewer into the physical space of the data, making global datasets, such as the deforestation or migration, accessible as personal experiences of scale and impact.

6.3. BALANCING ABSTRACTION, ACCURACY, AND EXPRESSIVE INTENT

The paradox of data-sculptural practice is to effect a ratio between the abstraction, the accuracy and expressiveness. Total fidelity of information ensures informational integrity but may produce graphically rigid or impossible information, and excessive abstraction may result in an absence of meaning. Balance is an art form that involves the construction of the forms that would be true to the nature of the dataset and promote the interpretive interaction. Cognitive intelligibility and aesthetic richness are not sacrificed in the selective simplification, scaling and metaphorical translation process of designers. This process of simply viewing complexity in order to perceive patterns that can be understood in order to make the mind to know about the general relationships is the abstraction of visual language. Nevertheless, these abstractions are grounded in accuracy which makes them remain proportionate, have relational integrity and structural hierarchy to enhance credibility. The expressive aspect, in its turn, adds human touch to the sculpture, which is achieved as a result of material symbolism, movement, and rhythm. This tripartite accord necessitates the refinement process and precision of calculations is joined with the instinct of art. Algorithms can achieve quantitative consistency, whereas interpretive hierarchy is maintained by the designer, and he or she decides the fineness of the data that will take the lead in the visual narrative.

7. CONCLUSION

Sculptural art form of data visualization redefines human perceptions, interpretation as well as experiences with respect to information. It permeates conventional divisions of charts, graphs, computer displays in that it brings data to life in the form of corporeal and spatial narratives that incorporate analytical precision and beauty. The synthesis of computational modeling, machine learning, and digital fabrication produces abstract datasets in a touchable, explorable, and emotionally engaging form to represent them as sculptural embodiments. A combination of science, technology and art such like this enables the information to speak more than mind to stimulate feeling, compassion and thought. It is pointed out in the paper that physicalization of data is not a visualization process, however, it is a process of translation and transformation. It decodes numeric logic at a sensual level, between the spiritual realm of digital information and material realm of material space. All sculptural manifestations of expression become a dialogue between accuracy and fantasy and cause the viewers to think about the hidden rhythms of how the mechanisms structure our reality, society, and emotions. However, it is not an easy process and fidelity, issues of scale, sustainability and interpretive ambiguity are still present. However, such limitations also contribute to resourceful problem solving, which creates cross-disciplinary collaboration of artists, designers, engineers, and data scientists. The chance of dynamic, interactive and adaptable sculptures is even increasing with the development of fabrication technologies.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

REFERENCES

Arrighi, G., See, Z. S., and Jones, D. (2021). Victoria Theatre Virtual Reality: A Digital Heritage Case Study and User Experience Design. Digital Applications in Archaeology and Cultural Heritage, 21, e00176. https://doi.org/10.1016/j.daach.2021.e00176

Bekele, M. K., Pierdicca, R., Frontoni, E., Malinverni, E. S., and Gain, J. (2018). A Survey of Augmented, Virtual, and Mixed Reality for Cultural Heritage. Journal on Computing and Cultural Heritage (JOCCH), 11, 1–36. https://doi.org/10.1145/3167132

Ceccotti, H. (2022). Cultural Heritage in Fully Immersive Virtual Reality. Virtual Worlds, 1, 82–102.

El-Said, O., and Aziz, H. (2022). Virtual Tours as a Means to an End: An Analysis of Virtual Tours' Role in Tourism Recovery Post COVID-19. Journal of Travel Research, 61, 528–548. https://doi.org/10.1177/00472875211024893

Lo Turco, M., Giovannini, E. C., and Tomalini, A. (2022). Parametric and Visual Programming BIM Applied to Museums, Linking Container and Content. ISPRS International Journal of Geo-Information, 11, 411. https://doi.org/10.3390/ijgi11070411

Luther, W., Baloian, N., Biella, D., and Sacher, D. (2023). Digital Twins and Enabling Technologies in Museums and Cultural Heritage: An Overview. Sensors, 23, 1583. https://doi.org/10.3390/s23031583

Maiwald, F., Lehmann, C., and Lazariv, T. (2021). Fully Automated Pose Estimation of Historical Images in the Context of 4D Geographic Information Systems Utilizing Machine Learning Methods. ISPRS International Journal of Geo-Information, 10, 748. https://doi.org/10.3390/ijgi10120748

Monaco, D., Pellegrino, M. A., Scarano, V., and Vicidomini, L. (2022). Linked Open Data in Authoring Virtual Exhibitions. Journal of Cultural Heritage, 53, 127–142. https://doi.org/10.1016/j.culher.2021.11.002

Nisiotis, L., Alboul, L., and Beer, M. (2020). A Prototype That Fuses Virtual Reality, Robots, and Social Networks to Create a New Cyber–Physical–Social Eco-Society System for Cultural Heritage. Sustainability, 12, 645. https://doi.org/10.3390/su12020645

Pisoni, G., Díaz-Rodríguez, N., Gijlers, H., and Tonolli, L. (2021). Human-Centered Artificial Intelligence for Designing Accessible Cultural Heritage. Applied Sciences, 11, 870. https://doi.org/10.3390/app11030870

Pourmoradian, S., Farrokhi, O. S., and Hosseini, S. Y. (2021). Museum Visitors' Interest on Virtual Tours in COVID-19 Situation. Journal of Environmental Management and Tourism, 12, 877–885.

Rahaman, H., Champion, E., and Bekele, M. (2019). From Photo to 3D to Mixed Reality: A Complete Workflow for Cultural Heritage Visualisation and Experience. Digital Applications in Archaeology and Cultural Heritage, 13, e00102. https://doi.org/10.1016/j.daach.2019.e00102

Rauschnabel, P. A., Felix, R., Hinsch, C., Shahab, H., and Alt, F. (2022). What Is XR? Towards a Framework for Augmented and Virtual Reality. Computers in Human Behavior, 133, 107289. https://doi.org/10.1016/j.chb.2022.107289

Theodoropoulos, A., and Antoniou, A. (2022). VR Games in Cultural Heritage: A Systematic Review of the Emerging Fields of Virtual Reality and Culture Games. Applied Sciences, 12, 8476. https://doi.org/10.3390/app12228476

Willkens, D. S., Haley, H. M., and Liu, J. (2020). Race, Space, and Digital Interpretation at Selma's Old Depot Museum. Arris, 31, 108–118.