인간화 미학에 기반한 컴퓨팅 미학에 관한 연구

건축 디자인을 중심으로

A study on the Computational Aesthetics based on Humanized Aesthetics

Focusing on the architectural design

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Abstract

In recent years, computational aesthetics, which connects science and art, is becoming a new interdisciplinary field that brings technology into art creating. With advanced CAD technology and artificial intelligence, computational aesthetics has been widely used in many design fields such as architecture and industry design. Famous design companies such as Foster+Partners, Zaha Hadid and BIG have already adopted computational and parametric design method as a competitive way to enhance creativity. But there are still some argues that this new aesthetics is superficial or even cold. In terms of generative art, as an advanced digital art, reveals a new aesthetic power, which is impressive. In this context, the purpose of the study aims at comparing computational aesthetics with aesthetics to reveal their differentiation and correlation that benefit for designer to fresh the cognition of this new approach vice versa. As methods of this research, firstly previous researches and literature are collected and comparatively analyzed on the concept and relationships of aesthetics and computational aesthetics, as well as the assessment method. Secondly, through case studies, under the characters of these two aesthetic approaches in design field, three representative cases are selected to be deeply investigated by collecting and analyzing relevant articles, books and online materials to explain the respective features. Then, after comparison and further analysis, explaining how computational aesthetics as a rational aesthetic expression can augment the limit of human aesthetic experience and the design thinking process. The final results of this paper point that aesthetics dominated by emotional mind belongs to a top-down thinking process, while computational aesthetics because of its algorithmic generated basis, which dominated by logic mind, it belongs to a bottom-up thinking process. It is expected that the findings based on this research can provide certain guidance for designers to make good use of them.

Keyword

Aesthetics(미학), Computational Aesthetics(컴퓨터 미학), Algorithmic Aesthetics(알고리즘 미학)

요약

최근 과학과 예술을 연결하는 계산 미학은 기술을 예술 창조에 가져다주는 새로운 학제적 분야가 되고 있다. 첨단 CAD 기술과 인공 지능으로 인해 계산 미학은 건축 및 산업 디자인과 같은 많은 설계 분야에서 널리 사용된다. Foster+Partners, Zaha Hadid, BIG 등의 유명한 디자인 회사는 창의력을 높이기 위한 경쟁력 있는 방법으로 이미 계산 및 파라메트릭 디자인 기술을 채택하고 있다. 그러나 이 새로운 미학은 표면적이거나 심지어 차가워진다는 주장도 있다. 일반 예술의 경우, 고급 디지털 아트로 인상적인 새로운 미적 힘을 드러낸다. 이 맥락에서 연구의 목적은 계산 미학을 미학과 비교하여 설계자가 이 새로운 접근법의 인식을 새롭게 하는 데 도움이 되는 차별화와 상관관계를 밝히는 것을 목표로 한다. 이 연구의 방법으로 먼저 이전 연구와 문헌을 수집하고 미학과 계산 미학의 개념과 관계 및 평가 방법을 비교 분석한다. 둘째, 사례 연구를 통해 디자인 분야에서 이러한 두 가지 미적 접근법의 특징에 따라 관련 기사, 책 및 온라인 자료를 수집하고 분석하여 각 특징을 설명함으로써 세 가지 대표적인 사례를 선택하여 자세히 조사한다. 그런 다음 비교와 추가 분석 후 합리적인 미적 표현으로서의 계산 미학이 인간의 미적 경험과 디자인 사고 과정의 한계를 어떻게 증가시킬 수 있는지 설명한다. 이 논문의 최종 결과는 감정적인 마음에 의해 지배되는 미학은 하향식 사고 과정에 속하며 논리적인 마음에 의해 지배되는 알고리즘에 의해 생성된 기초 때문에 계산상 미학은 상향식 사고 과정에 속하는 것을 보여준다. 이 연구에 기초한 연구결과는 설계자가 이를 잘 활용할 수 있도록 일정한 지침을 제공 할 수 있을 것으로 기대된다.

목차

1. Introduction

Many influential movements dominated the world's aesthetical sense for certain periods, in the history of architecture, from the classic Gothic style, Barroco style, Rococo style to modernism Bauhaus, aesthetic style copping with social context comes out and fades away then making room for new ideas. In the 4th Industrial Revolution, the rapid development of computer technology has become the driving power to change the design thinking and making. Architects transitioned from pencil sketches and blueprints to the use of computer-aided design methods, from the rigid Euclid geometry to computational free-forming, a new style as computational aesthetics occupies design both in theory and practice in contemporary society. This increased expressive power, compounded with highly advanced computational power, has created tremendous opportunities for the realization of computational aesthetics beyond human perception.

2. Aesthetics

2-1. Definition of Aesthetics & Aesthetic Experience

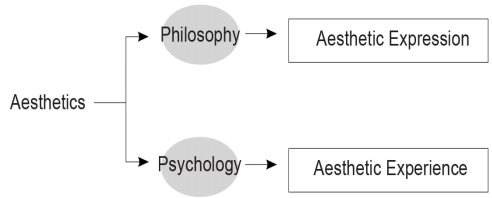
Aesthetics(humanized aesthetics) has been the subject of long-standing debates by philosophers and psychologists. For instance, Greek philosopher Plato introduced such a view: “Beauty lies in the eyes of the beholder.” While according to the Oxford Advanced Learner’s Dictionary, aesthetics means “concerned with beauty and art and the understanding of beautiful things”, and “made in an artistic way and beautiful to look at”.Aesthetics is now widely accepted in almost any encyclopedia to be defined as "the philosophical study of beauty

and taste".[1] Currently used definitions of aesthetics is from The American Heritage Dictionary of the English Language (Fig.1):

1) the branch of philosophy that deals with the nature and expression of beauty.

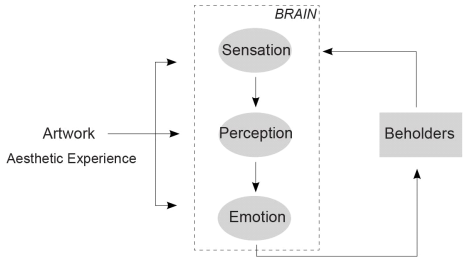
[Fig 1] Two Branches of Aesthetics

2) the study of the psychological responses to beauty and artistic experiences.[2]



[Fig 1] Two Branches of Aesthetics

In psychology, it is generally agreed that aesthetic experience results from an interaction between perception, cognition, and emotion.[3] Although the appreciation of beauty is an innate ability of humans, personal growth background, culture, and education would still result in differences in individual perceptions(Fig. 2).[4] In fact, aesthetics is known to depend on cultural context and to be a subjective experience and an intuitive concept that eludes quantification.[5]



[Fig 2] Aesthetic Experience

In science, aesthetic cognition of humans is formed by mutual recognition of the ventral and dorsal pathways(Fig. 3). The recent fMRI studies have also shown that these two pathways have complementary response capabilities in recognizing visual stimuli.[6] The beauty perceived by the ventral pathway is a "common" beauty, which can be stimulated to a certain extent by cognitive objects, while the dorsal pathway is based on common beauty perception, then strengthened by one's own experience and knowledge to generate a higher degree of beauty perception.[7]

1) Florian Hoenig, Computational Aesthetics in Graphics, Visualization and Imaging, The Eurographics Association, 2005, p.13.

2) Dhiraj Joshi, Ritendra Datta, Elena Fedorovskaya, Quang-Tuan Luong, James Z. Wang, Jia Li, and JieboLuo, "Aesthetics and Emotions in Images", IEEE Signal Processing Magazine, 2011,Vol.22 pp.94-115.

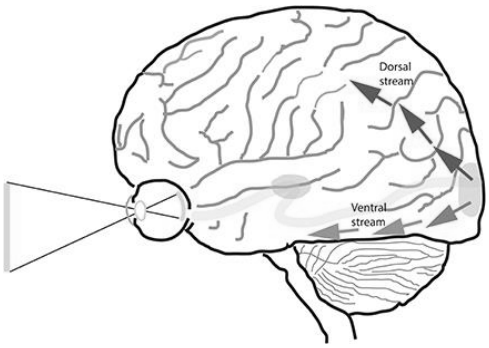
3) Frontiersin, (2021.12.03.) URL: https://www.frontiersin.org/articles/10.3389/fncom.2017.00102/full

4) Chia Yao Kung, A Study on the Visual Characteristics and Preference for Architectural Exterior Materials , Focusing on the Theory of Neuroaesthetics and Evloutionary Aesthetics, Korea Institute of Design Research Society, 2021, Vol.6 No.4, pp.30-51

5) David M. Berry & Michael Dieter, Thinking Postdigital Aesthetics: Art, Computation and Design, Palgrave Macmillan, 2015, Vol.1, No.1, p.11.

6) Chia Yao Kung, A Study on the Visual Characteristics and Preference for Architectural Exterior Materials , focusing on the theory of neuroaesthetics and evloutionary aesthetics, Korea Institute of Design Research Society, 2021, Vol.6, No.4, pp. 30-51.

7) Ibid., p.35.



[Fig 3] The Dorsal and Ventral Streams of the Visual Pathway

2-2. Aesthetics and Design

Aesthetics as an extension of visual perception plays a major role in the design, complementing the function and improving the value of the products in many ways. A good attractive design supports our understanding of complex functional products and helps us seamlessly integrate them into an environment. Don Norman pointed that attractive things make people feel good, which in turn makes them think more creatively.[8] Chatterjee has also suggested that the emotions involved in aesthetic experience might be related to a reward system of pleasure subserved by opioid and cannabinoid neurochemical systems.[9] That means aesthetics enhance productions' function unconsciously through broadening humans' creative thinking via the aesthetic pleasure experience.

As illustrated by Don Norman in his book "Emotional Design", there are three different levels of design: visceral, behavioral, and reflective(Fig. 4). When we perceive something like "pretty", that judgment comes directly from the visceral level which is immediate emotional impact. The sign of "feel good and look good" could be directly connected to the "wow experience". Due to aesthetic effect on our brain, the positive effect enhances creative, width-first thinking, and products's usability get enhanced through pleasant, aesthetic appearance. "Aesthetics matter: attractive things work better," said by Don Norman.

[Fig 4] Don Norman_3 Levels of Design Appeal

[Fig 4] Don Norman_3 Levels of Design Appeal

2-3. Aesthetics and Aesthetic Value

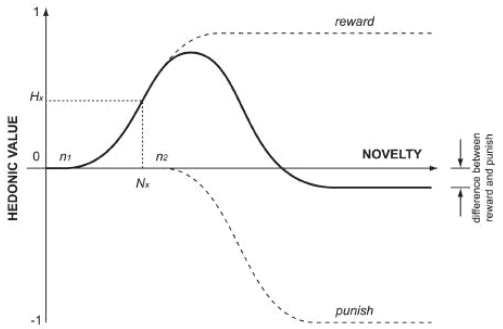
Beauty is a subjective phenomenon, depending on the attitude of the observer, while others treat aesthetics to be objectively existing and universal.[10] An explainable aesthetics makes it

8) Donald A. Norman., Emotional Design: Why We Love (Or Hate) Everyday Things, Basic Books, 2004, p.19.

9) M., Pearce, D. Zaidel, O. Vertanian, M. Skov, H. Lder, A. Chatterjee,& M. Nadal,Neuroaesthetics:The Cognitive Neuroscience of Aesthetic Experience, Perspectives on Psychological Science, 2016. Vol.11, No.2, p.13.

10) Dhiraj Joshi, Ritendra Datta, Elena Fedorovskaya, Quang-Tuan Luong, James Z. Wang, Jia Li, and

possible for a creator to communicate value to others.[11] It can be inferred that aesthetics is the value that imposed to art pieces by creator. One way quantitatively to measure aesthetic value is the Wundt Curve(Fig. 5) by Berlyne in 1970.[12] Initially value increases as new ideas and features are incorporated into the artifact. As the novelty of an artifact increases, the artifact becomes so new that it begins not to fit the domain and the value decreases until it is no longer of interest. Along with the adding of new ideas and features, the purpose of aesthetics is to impose creative value to art pieces by creator. According to the Wundt Curve, creativity is necessary to judge a piece of art as successful or not[13].



[Fig 5] The Wundt Curve

2-4. Sensation and Perception

Referred to visual information, we don't "see" with our eyes, we see with our brain. As a part of the brain itself formed in utero from neural tissue, the retina isn't a passive pathway[14] of visual information. It is derived from the neural tube and is part of central nervous system. Numerous advanced studies have confirmed that the brain processes visual stimuli by receiving them from the retina and transmitting to the primary visual cortex through the lateral geniculate nucleus.[15] Visual information will be conveyed to corresponding areas via the ventral and dorsal pathways. The information via ventral pathway will eventually reach the inferior temporal cortex. It exhibits susceptible and high-resolution selective features for characteristics such as shape, pattern, and colo r.[16] This information could be interpreted as feature detectors which responsible for short-term visual memory as sensation. The dorsal stream flows into the posterior parietal cortex, which is responsible for language and vision, and received visual information through long-term memories to emerge semantic associations, thereby forming cognition of things regarded as perception. Sensation is the conversion of energy from the environment into a pattern of response by the nervous system, and perception is the interpretation of that information(Fig. 6).[17] The recent fMRI studies have also shown that these two pathways have complementary response capabilities in recognizing visual stimuli.[18] According to psychology, our ability to perceive something in more than one way is the basis of Gestalt

JieboLuo, "Aesthetics and Emotions in Images", IEEE Signal Processing Magazine, 2011,Vol.22, pp.94-115.

11) Paul Bodily & Dan Ventura, Explainability: an Aesthetic for Aesthetics in Computational Creative Systems, ICCC, 2018.

12) Berlyne, D.E., "Novelty, Complexity, and Hedonic Value", Perception & Psychophysics, 1970, Vol.8, No.5, pp.279-286.

13) Paul Bodily & Dan Ventura, Explainability: an Aesthetic for Aesthetics in Computational Creative Systems, ICCC, 2018

14) Amy E. Herman ,Visual Intelligence, Harper One, 2017, p.23.

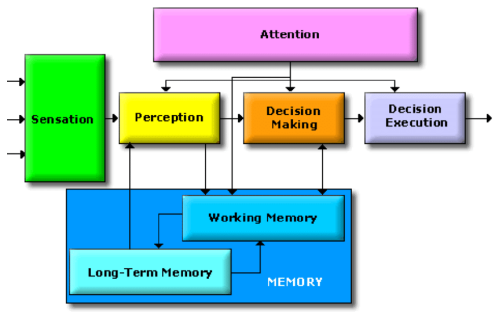
15) A.,Bartels, & S., Zeki, The Theory of Multistage Integration in the Visual Brain, Proceedings of the Royal Society B: Biological Sciences, 1998,Vol.265, No.1412, p.1.

16) https://elifesciences.org/articles/32259, (2022.04.20.)

17) James W. Kalt., Introduction to Psychology, Cengage Learning, 2017, p.130.

18) Eisenman P., Visions' Unfolding: Architecture in the Age of Electronic Media, Domus,1992, Vol.734, pp.17-24.

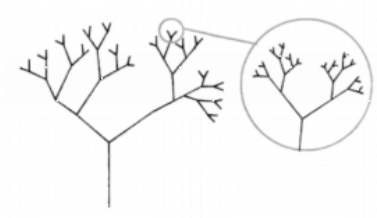
psychology, a field that emphasizes the perception of overall patterns.[19] Gestalt psychology does not deny the importance of feature detectors but insists that feature detectors are not enough. Perceiving a pattern depends on context, not just adding up feature detectors. Feature detectors represent a bottom-up process, in which tiny elements combine to produce larger items. However, perception also includes a top-down process, in which you apply your experience and expectations to interpret each item in context.



[Fig 6] Example of a Simplified Human Information Processing Model Used by the FAA

2-5. Aesthetic Codes in Nature

Ethologist Morris stated that symmetrical or repetitive visual patterns are the elements that can grab human's attention.[20] Fractal theory is an existing example of repeating similar element which wildly exists in natural beauty. In 1967, Benoit Mandelbrot proposed the self-similarity in papers such as "How Long is the Coast of Britain?","Statistical Self-Similarity and Fractional Dimension", and in 1975, he created the fractal theory and studied the property and application of fractals.[21] The basic principle of fractals is that mathematical objects whose structure stays the same after changing the scale of itself(Fig7).



[Fig 7] Fractals Example

In general, rewriting is a technique for defining complex objects by successively replacing parts of a simple initial object using a set of rewriting rules or production."[22] In other words, fractals is a technique for defining complex objects by successively repeating a simple initial object using rewriting rules. In nature, the fractals developed from the outline of the mountain ridges and clouds are all patterns and orders that exist in nature.[23] The structural codes of various trees, leaves, landscapes and natural phenomena have existed in the perception of the brain since the past which evolved to current human preference for specific patterns. In 1968, Hungarian botanist Aristid Lindenmayer developed a grammar-base system to model the growth patterns of plants name as L-systems[24]

19) James W. Kalt., Introduction to Psychology, Cengage Learning, 2017, p.129.

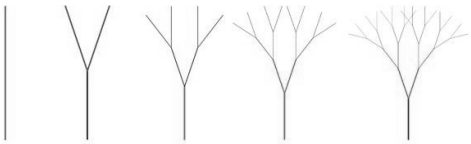
20) M., Lee, & T. Cho, "A Study on the Order of the Spatial Shape based on Neurology", Korea Society of Basic Design and Art, 2016, Vol.17, No.4, p.322.

21) Wikipedia, (2022.03.07.), URL:https://en.wikipedia.org/wiki/Fractal

22) The McGraw-Hill Compaines, Computer Graphics, Tata McGraw-Hill Publishing Company Limited and UPTEC Computer Consultancy Limited, 2006, p.206

23) S., Yun,& T., Cho, Understanding the Order of the Natural Shape and a Public Space Design as the Universal Beauty, Journal of Korean Institute of Spatial Design, 2011, Vol.5, No.7, pp.29-36.

24) Medium, (2021.12.03), URL: https://medium.com/@hhtun21/l-systems-draw-your-first-fractals-139ed0bfcac2



[Fig 8] L-System

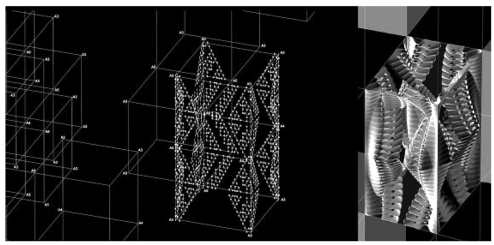
We see a possibility of simulating the natural beauty in a mathematic way within human understanding. Simply rewriting codes into complicated structure is the central rules of natural aesthetics and creates fantastic expressions. Like digital philosophers, Schmidhuber argued that if the universe was computable, then there had to be a computational aesthetics running beneath all physical phenomena: an under-pinning, foundational, mathematical beauty that could be expressed by the shortest of codes accessible to an observer.[25]

3. Computational Aesthetics

3-1. Definition of Computational Aesthetics

Computation is a term that differs from computerization or digitalization. It is the procedure of calculating and determining something by mathematical or logical methods, computerization is the act of entering, processing, or storing information in a computer or a computer system.[26] It is also pointed that computation is about the exploration of indeterminate, vague, unclear, and often ill-defined processes that aims at emulating or extending the human intellect. [27]

In the field of computer science, computational aesthetics, related to computation, has entered the field of aesthetics. Computational aesthetics aims to solve the problems of how computers could generate various visual aesthetic expressions or evaluate aesthetics of various visual expressions automatically.[28] Computational aesthetics is dedicated to understanding mathematical simulation.[29] As a new aesthetic style, the dismissing of it superficial is inappropriate because the increasing ubiquity of digital technologies affects both our material culture and our living style. As the manifestation of computational aesthetics, the form stands for the expression of parameters and rules, visually impacts people's feelings, as if this design is a force beyond human control.[30]



[Fig 9] Brandon Williams, Expression of Code

3-2. History of Computational Aesthetics

The birth of computational aesthetics is often attributed to George David Birkhoff's book “Aesthetic Measure” (Birkhoff, 1933), although the book does not mention the term itself. As an American mathematician, he proposed the

25) Luciana Parisi, Contagious Architecture, Computation, Aesthetics, and Space, the MIT Press, 2013, p.66.

26) Kostas Terzidis, Expressive Form, a conceptual approach to computational design, Spon Press, 2003, p.70.

27) Ibid.,p.69.

28) Yihang Bo, Jinhui Yu & Kang Zhang, Computational Aesthetics and Applications, Visual Computing for Industry, Biomedicine, and Art, 2018, Vol.1, No.6, pp. 3-19.

29) Michael Bauerly & Yili Liu, Computational Modeling and Experimental Investigation of Effects of Compositional Elements on Interface and Design Aesthetics, J.Human-Computer Studies,2005, Vol.64, pp.670-682.

30) Van Nostrand Reinhold. Postdigital Aesthetics: Art, Computation and Design, Springer, 2015.

formula M = O/C where M is the "aesthetic measure," O is order, and C is complexity. Birkhoff's formula is considered to be the forefather of modern computational aesthetics.

In the 1950s, German philosopher Max Bense and French engineer Abraham Moles independently combined Birkhoff's work with Claude Shannon's information theory to develop a scientific means of grasping aesthetics.[31] While these ideas did not feel close to human perception. As early as September 1964, Kawano published the first designs he had calculated with the aid of the "OKITAC 5090A computer" at the University of Tokyo in "IBM Review", a Japanese professional journal. The Japanese philosopher, Kawano's was neither artist nor engineer but a philosopher. With the help of technology, he began exploring the logic of artistic creation through the experimental generation of pictures, poetry, sculptures, and music. In the early 1990s, the International Society for Mathematical and Computational Aesthetics (IS-MCA) was founded. In the 21st century, computational aesthetics is an established field with its own specialized conferences, workshops, and special issues of journals uniting researchers from diverse backgrounds, particularly AI and computer graphics. Computational aesthetics has been applied in a number of different fields for various purposes. The final verdict in delicate aesthetic assessments, however, is usually left to human or human experts.

3-3. Algorithmic Aesthetics

Generative art as a manifestation of computational aesthetics is inevitable to discuss. According to Wikipedia, "Generative art" often refers to "Algorithmic art" that algorithms determine computer to generate artwork. Many algorithms are simulations of natural processes and as such they must not be regarded as human inventions but rather as human discoveries.[32] Unlike inventions, discoveries are not conceived, owned, or controlled by the human mind, yet as abstract processes they can be captured, codified and executed by a computer system. The process is occurring in nature regardless of the presence of humans. In these algorithmic processes, their behavior is often non-predictable and that frequently they produce patterns of thought and results that amaze even their own creators.[33] Clarified by Brandon Williams, algorithms do not give us representations of spatial experience, but are computational processes that can be used to generate unseen structures and unlived events.[34] In Fig.9, abstract code consisting of As and Bs realizes and becomes realizable surface and structure through modes of transposition and the shape is changeable along with points.

Aesthetics in computation coincides not with notions of perception but with transcendental ideas of beauty, and represented in geometric models of linearity and symmetry.[35] In its simplest form, a computational algorithm uses numerical methods to address problems. Unlike computerization and digitization, the extraction of algorithmic processes is an act of high-level abstraction. Kostas Terzidis(was associate professor at Harvard University GSD) observes that algorithmic processes extend beyond the limits of human perception, and high abstraction of algorithms shows out an unlimited expression. Nevertheless, algorithmic structures represent abstract patterns that are not necessarily

31) https://medium.com/sciforce/computational-aesthetics-shall-we-let-computers-measure-beauty-db2205989fb, (2021.12.03.).

32) Kostas Terzidis, Algorithmic Architecture, Elsevier Ltd, 2006, p.19.

33) Kostas Terzidis, Expressive Form, a conceptual approach to computational design, Spon Press, 2003, p.68.

34) Ingeborg M. Rocker, When Code Matters, Architectural Design, 2006, Vol.76, No.4, pp.16-25.

35) Luciana Parisi, Contagious Architecture, Computation, Aesthetics, and Space, the MIT Press, 2013, p.157.

associated with experience or perception.[36] Like digital philosophers, Schmidhuber also argued that if the universe was computable, then there had to be a computational aesthetics running beneath all physical phenomena: an under-pinning, foundational, mathematical beauty that could be expressed by the shortest of codes accessible to an observer.[37] From this standpoint, computational aesthetics is the manifestation of an elegant compression of complex data which not invented by human but discovered by human.

This possibility opens up a more intricate relationship between design and algorithm than has been previously possible. Rather than using algorithms to copy, simulate, or replace manual methods of design, instead they can be studied as methodologies that operate in ways similar, parallel, or complementary to that of the human mind. Second, along the lines of homo faber, algorithms can be seen as design tools that lead towards the production of novel concepts, ideas, or forms, which, in turn, have an effect in the way designers think thereafter.[38] In this way, such inductive algorithms can be regarded as extensions to human thinking and therefore may allow one to leap into areas of unpredictable, unimaginable, and often inconceivable potential. Algorithms are not the end product, but rather a vehicle for exploration. As algorithms advance, they abstract complexity out of many steps of design and making into simpler actions. Algorithms reduce the number of steps to design something by allowing designers to focus on the bigger picture.

3-4. Computational Creativity

Compared to creativity, computational creativity is the study of building software that exhibits behavior that would be deemed creative in humans. Such creative software can be used for autonomous creative tasks, such as inventing mathematical theories, writing poems, painting pictures, and composing music. A creative system often imitates characteristics of human creativity leading people to recognize that the system has a consciousness that impels its creative behavio r.[39] However, along with technology development, computers not only beat humans at arithmetic calculation but also the possibility of human-level image recognition. It changes the role of simply accomplishing the appointed tasks but turns to exsert real simulated human creativity.

Generative systems can be considered as an computational aid to support humans in achieving unlimited creativity. Compared to creativity (Table.1), computational creativity is the result of generative system that exhibits simulated behavior that would be deemed as creative as humans. It is highly possible, computers are more possible to access unlimited creativity than humans because of the unlimited computational power. Computational creativity strips from the human conscious and is highly reliant on generative systems running by algorithms. It has been characterized as “computational systems which by taking on particular responsibilities, exhibit behaviors that unbiased observers would deem to be creative ”.[40]

36) Ibid. p.49.

37) Jürgen Schmidhuber, Simple Algorithmic Principles of Discovery, Subjective Beauty, Selective Attention, Curiosity and Creativity, Discovery Science: 10th International Conference (Berlin: Springer,), 2007, pp.26－38.

38) Kostas Terzidis, Algorithmic Architecture, Elsevier Ltd, 2006, p.20.

39) Paul Bodily & Dan Ventura, Explainability: an Aesthetic for Aesthetics in Computational Creative Systems, ICCC, 2018.

40) Simon Colton & Ceraint A. Wigins, Computational creativity: The final frontier?, In Proceedings of the European Conference on Artificial Intelligence, 2012, Vol.12, pp.21-26.

Table 1. Comparison between Creativity and Computational Creativity

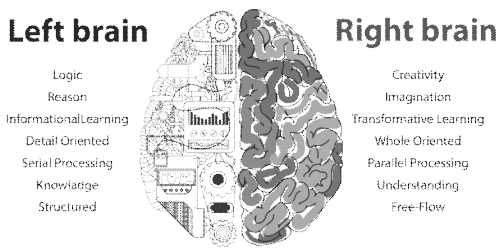
	Creativity	Computational Creativity
Amount	Limited	Unlimited
Generation	Subconscious	Algorithms
Context	Culture	Computational System
Direction	No	Yes
Complexity	Limited Complexity	Unlimited Complexity
Control	Without	Algorithms Control

4. Comparison between Humanized Aesthetics and Computational Aesthetics

Reviewing the birth of computational aesthetic assessment, it is viewed as a measure formula which exhibits aesthetic assessment. Proposed by Birkhoff, the formula M = O/C where M is the "aesthetic measure," O is order, and C is complexity. In particular, computational aesthetics computing relies on the idea that the shortest program used to calculate infinite complexity is the most eloquent expression of harmony and elegance in mathematics.[41]

Computational aesthetics does not pay attention to the area of human emotion evoked by artpieces but focuses on the editing process of codes. This rational beauty is based on the predictability of results, where the more compressed the data, the greater the chance of patterns remaining regular, periodic, calculable, operational, and effective. This new aesthetics is not a process of prehension, but merely corresponds to already made and endlessly repetitive patterns, the simple functions that engender complex behaviors.[42] The more compressible, predictable, and cognized an algorithmic form is, the more beautiful it is.[43]

As we discussed before, aesthetic experience is combined with the changing status of the beholder's emotion. Emotional response is a powerful motivating force for human behavior.[44] In design, the "wow experience" immediately happens when we see some beautiful things even we do not know what (refers to logic thinking) it is. Our emotions have a mind of their own, one which can hold views quite independently of our rational mind. As for aesthetic perception, personal experiences and cultural backgrounds are required to interpret visual information. On contrary, computational aesthetics pays attention to the algorithmic processes which extend beyond the limits of human perception, their inductive strategy is to explore generative processes or to simulate complex phenomena. Such inductive algorithms can be regarded as extensions to human thinking and therefore may allow one to leap into areas of unpredictable, unimaginable, and often inconceivable potential.[45]



[Fig 10] The Left Brain & Right Brain

Biologically, there are two hemispheres in our brain, the left side is rational, analytic, and logical while the right side is mute, nonlinear,

41) Paul Churchland, Neurophilosophy at Work, Cambridge University Press, 2009, p.33.

42) Luciana Parisi, Contagious Architecture, Computation, Aesthetics, and Space, the MIT Press, 2013, p.67.

43) ibid. p.69

44) K., Han, Re-Examining the Savanna Hypothesis in Terms of Scenic Beauty, Preference and Restoration, Journal of Geographical Science, 2005, Vol.41, p.27.

45) Kostas Terzidis, Expressive Form, A conceptual Approach to Computational Design, Spon Press, 2003, p.69.

and instinctive.[46] The left hemisphere analyzes the details, the right hemisphere synthesizes the big picture. We usually accept art as the right brain's activity, and it is more connected to emotion; while computational aesthetics is a result of left-brain activity because of algorithmic generation. For some cases, algorithms is becoming a rationalized version of human thinking. As such it may be characterized as being precise, definite, and logical, but at the same time may also lack certain unique qualities of human sensibility. As main difference, aesthetics relies on the human creativity belongs to right brain's activity while computational aesthetics created by generative algorithms could be regard as left brain's activity.

Table 2. Comparison between humanized aesthetics and computational aesthetics

	Aesthetics	Computational Aesthetics
Order	Gestalt Principle	Algorithms
Complexity	Creation	Algorithms Output
Control	Human	Algorithms
Perception	High Connected	Low Connected
Source	Human Creativity	Computational Creativity
Mind	Emotional	Rational

5. Case Studies

5-1. Overview of the Cases

In nowadays, design computation, the use of computation to generate and analyze form and performance, seems to mark a change in the way designers think. For architecture, as early as the 1880s, Bauhaus as a cultural movement opened a new era of modernism instead of conservatism from Germany to worldwide. As the growth of computer technology from 1960 to now, computational architecture opened a new era of "Parametricism" . That is a start that with design computation, designers have the possibility to create a framework within which they can generate and explore more different design alternatives than before. For the study of computational aesthetics, in the background of shifting to computational power in design, three cases are selected to make comparison and analysis. In architecture, the Bauhaus building represents the start of modernism and turns into a traditional aesthetic trend dominated by simplicity for last 100 years. Second case with high complexity is from Zaha Hadid studio which shows a computational aesthetic view compared to Bauhaus style with linear and Euclid. As an example of high standard of generative design, "avocado armchair" shows a new approach of achieving automatically algorithmic design. These three cases with three different design methods and represents a changing step from modernism to contemporary machine learning era.

5-2. The Bauhaus Building

[Fig 11] The Bauhaus Building

The Staatliches Bauhaus, commonly known as the Bauhaus, was a German art school operational from 1919 to 1933 that combined crafts and the fine arts, and school became famous for its approach to design, which attempted to unify the principles of mass

46) Daniel H. Pink, A Whole New Mind: Why Right-brainers Will Rule the Future, Riverhead Books, 2005, p.13.

production with individual artistic vision and strove to combine aesthetics with everyday function.[47] The building was designed by the founder of the Bauhaus, Walter Gropius, and commissioned by the city of Dessau. The building was first listed in 1972 and the subsequent award of UNESCO World Heritage status in 1996 led to a comprehensive programme of renovations.[48] Bauhaus style is commonly characterized as a combination of the Arts and Crafts movement with modernism, as evident in its emphasis on function. Thus, typical Bauhaus designs feature little ornamentation and show a focus on balanced forms and abstract shapes.[49] Furthermore, modern architecture design is heavily inspired by Bauhaus, which applies the clean lines and functional design. Bauhaus has some essential common characteristics as the key elements: eschewing ornamentation to focus on simple, rational, functional design; a focus on simple geometric forms, asymmetry favored over symmetry; use of steel, glass, concrete, and other modern materials; flat roofs; glass curtain walls; smooth facades.[50] The emphasis on volume and not mass is made clear by the extensive use of glass along the wall, leading to a more open and free form as modern design.[51]

In 1923, Bauhaus modernism clashed significantly with the dominant bourgeois taste of that time, which was characterized by eclecticism, cheap neo-classicist decoration. The new slogan is “art and technology a new unity” in combination with Louis Sullivan’s motto “form follows function,” the reduction of design to minimalist forms combined with a black and white interior as well as with simple basic colors characterized the Bauhaus legacy.[52]

5-2. ZHA’s Zaragoza Bridge Pavilion

[Fig 12] ZHA’s Zaragoza Bridge Pavilion

Zaragoza Bridge Pavilion is an enclosed interactive space spanning the River Ebro to form a gateway to the Zaragoza Expo 2008, a hybrid of pedestrian footbridge and exhibition pavilion. Four structural elements correspond to specific spatial enclosures, which intersect and brace each other. This fluid, dynamic design interprets the Expo’s theme:“Water and Sustainable Development”.[53]

The design approach requires both a facility with increasingly complex modeling systems and strong management skills: "Technology makes available more and more parameters, so we have to judge the relevance of data and strategize at a very early point in time."said by Fischer.[54] Sixty percent of ZHA’s employees have basic programming knowledge, and there are managers who help shepherd the design process. Instead of feeling overwhelmed by the glut of

47) Oxford Dictionary of Art and Artists, Oxford: Oxford University Press, 4th edn, 2009, pp.64－66.

48) Bauhaus, (2022.03.25.), URL: https://www.bauhaus －dessau.de/en/architecture/bauhaus-building.html,

49) Mymodernmet, (2022.03.25.), URL: https://mymodernmet.com/what-is-bauhaus-art-movement/

50) Thespruce, (2022.03.25.), URL: https://www.thespruce.com/what-is-bauhaus-architecture-4784133

51) Voice, (2022.03.25.), URL: https://voices.uchicago.edu/201504arth15709-01a2/2015/11/16/bauhaus/

52) Routledge, (2022.03.25.), URL: https://www.rem.routledge.com/articles/overview/bauhaus-1.

53) Zaha, (2022.03.25.),URL: https://www.zaha-hadid.com/design/zaragoza- bridge-pavilion/.

54) Tom Wujec, Imagine Design Create, Auto,Inc, 2011, p.154.

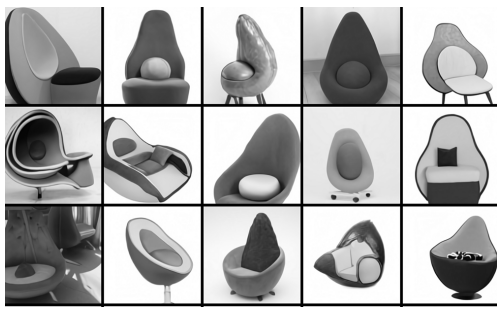
Table 4. Comparison of the investigated cases

Project Name	Bauhaus Building	Zaragoza Bridge Pavilion	Avocado Armchair
Designer	Walter Gropius	Zaha Hadid	OpenAI
Time	Since 1919	Since 2008	Since 2021
Output	3D	3D	2D
Category	Linear	Unlinear	Generative
Toolkit	Paper	Parametric Modeling	DALL-E
Input	Concept+Function	Parameters+Constrains	Language
Resource	Human	Computation	Computation
Style	Modernism	Parametricism	AI
Perception	Human Sensation	Human Sensation	Computation

information, In this project, parametric modeling use their increasingly content-rich data sets, visualized and understandable in highly intuitive 3D environments to get ever closer to design. And for a firm like ZHA, the realtime feedback regarding economic, structural, and environmental viability enables the clients who will sign on seemingly inconceivable programs. New computational design methods such as parametricism changes the manner of construction and level of efficiency. Karl Lagerfeld said of Zaha Hadid "She is the first architect to find a way to part with the all-dominating post-Bauhaus aesthetic, the potential of her imagination is enormous".[55]

5-3. An Armchair of Avocado Shape

Recently, OpenAI has released two models - DALL.E and CLIP. These models make use of a combination of language + images to make AI more efficient in understanding words and their meaning.[56] DALL-E (stylized DALL·E) is an artificial intelligence program that creates images from textual descriptions, revealed by OpenAI on January 5, 2021.



[Fig 13] An Armchair of Avocado Shape

When given this text caption, “An armchair of avocado shape”(Fig.13), DALL.E was able to come up with some outstanding armchairs carrying the shape of an actual avocado. DALL.E related the shape of a half avocado to the back of the armchair, and avocado pit to the cushio n.[57] Open AI's Aditya Ramesh said DALL·E "can take two unrelated concepts and put them together in a way that results in something kind of functional".[58] DALL·E was able to take inspiration from two unrelated ideas, while simultaneously creating something that takes into account the form and practicality of the final object. “We found that prompting DALL·E with the phrases ‘in the shape of,’ ‘in the form of,’ and ‘in the style of’ gives it the ability to do this.”[59]

55) ibid.p.157.

56) Aiworldschool,(2022.03.25.),URL: https://aiworldschool.com/a vocado-chairs-the-future-of-ai-technology

57) Openai, (2022.03.25.),URL:https://openai.com/blog/dall-e/

58) CACM, (2022.03.25.),URL:https://cacm.acm.org/news/249777-this-avocado-armchair-could-be-the-future-of-ai/fulltext?mobile=false

The test is meant to replace the Turing test as a benchmark for measuring artificial intelligence. It assumes that one mark of intelligence is the ability to blend concepts in creative ways. Asking a computer to draw a picture of a man holding a penguin is a better test of smarts than asking a chatbot to dupe a human in conversation, because it is more open-ended and less easy to cheat.[60]

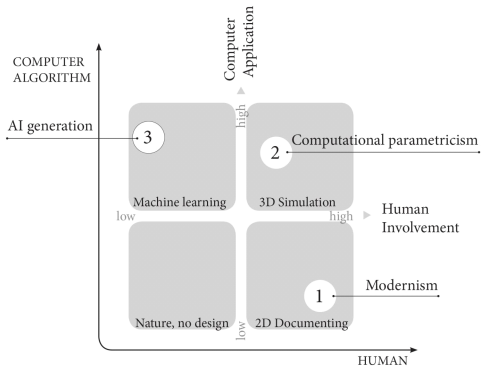
Needless to say, while there are still some weaknesses in the model to improve, DALL·E appears to be quite a versatile model with plenty of potential uses, and possibly any number of broad, unforeseen socio-economic impacts in the future.

5-4. Analysis and Result

The design innovations commonly associated with Gropius and the Bauhaus, the radically simplified forms, the rationality and functionality, and the idea that mass production was reconcilable with the individual artistic spirit, were already partly developed in Germany before the Bauhaus was founded. In Gropius's time, his style was to be functional, cheap and consistent with mass production. To meet this goal, decorations are rarely applied in modernism, and simplicity is dominated. The Bauhaus style tends to feature simple geometric shapes like rectangles and spheres, without elaborate decorations. As mentioned, the Bauhaus building featured little ornamentation and showed a focus on balanced forms and abstract shapes. While along with the development of industrial society, the Bauhaus modernism is finally acceptable because of matching the massive industrial production. Likewise the Bauhaus aesthetics clashed significantly with the dominant bourgeois taste of that time, ZHA's computational aesthetics is also critically pointed by modern society in the early age. However we can't ignore that computation is the only resource that has consistently dropped in price and vaulted in quantity and quality. In ZHA's case, we can indicate that, computers will have the power and patience to explore and evaluate thousands or millions of options that a human would never have the time to pursue, and explore solutions that a human designer might never think of. Because of the ability of controlling more complexity by algorithm, computational aesthetics show an astonished beauty beyond human perception. Recently, along with the fourth industrial revolution, machine learning and AI technology will definitely shift the dominated art style to "new form and new method" which matches new productive approaches. The appearance of "avocado armchair" in 2021 start the new generative design era somehow. Via generative system , designers could spend their time carefully formulating the goals and constraints of a project and describing them to a computer, and then computers use those descriptions to generate untold design permutations and human would choose the best-performing among them. Human design approach leads art to a way of simplicity as "modernism", however, stepping from the "parametricism" to "machining learning" age, technology will help us to explore more complicated shapes and forms in an easy way that we have never thought and experienced before(Fig. 14). Human designers could never work in such quantity, and in some cases, the computer discovers ideas that human might never consider.

59) Thenewstack, (2022.03.25.),URL:https://thenewstack.io/avocado-chairs-at-the-intersection-of-human-language-and-neural-networks/

60) Technologyreview, (2022.03.25.),URL: https://www.technologyreview.com/2021/01/05/1015754/avocado-armchair-future-ai-openai-deep-learning-nlp-gpt3-comp uter-vision-common-sense/

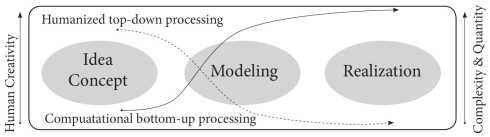


[Fig 14] Human and Computation (1.Modernism 2.Parametricism 3.Machining Learning)

5. Top-down & Bottom-up Processing

Traditionally, the dominant mode for discussing creativity in architecture has always been that of intuition and talent, where stylistic ideas are pervaded by an individual, a "star," or a group of talented partners within the practice. However algorithms are understood as abstract and universal mathematical operations that can be applied without pointed individual.

Like mathematics or geometry, computation is not an invention but rather a discovery. In other words, computation is of an independent nature and can be implemented on various devices including the computer or, to some extent, the human brain. Algorithms employ randomness, probability, or complexity the outcome of which is unknown, unpredictable, and unimaginable. An algorithm is not about perception or interpretation but rather about exploration, codification, and extension of the human mind. Both the algorithmic input and the computer's output are inseparable within a computational system of complementary sources. A bottom-up process is established among huge amount of data and algorithm will calculate for us. In this sense, synergy becomes the keyword as an embodiment of a process obtainable through the logic of mutual contributions: that of the human mind and that of the machine's extendibility.

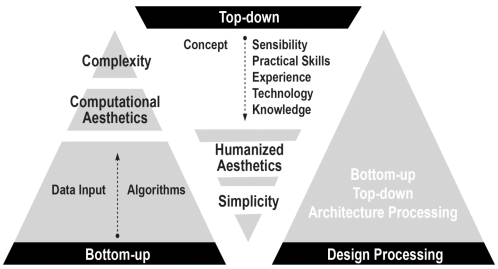


[Fig 15] Two Directions

Even though, physically, computers may appear to be a set of mindless connections, at the information level they are only a means of channeling mathematical and logical procedures. However, there is indeed a fundamental difference between the quantitative nature of computation and the abstract holistic nature of human thinking.

We could acknowledge that the appearance of computational aesthetics based on computational power and algorithms could be seen as an natural revolution process accompanying with the revolution of human society. We could not ignore that the natural difference exists between human abstract ability with algorithms. Computational aesthetics generated by algorithms which rooted in rational logical mind, however humanized aesthetics comes from human emotional mind and abstractive ability, and therefore these two elements have essential different. Finally, in the architectural design process(Fig.15), we could acknowledge humanized aesthetics derived from human perception belongs to a top-down process with numerous details initiated from one concept, finally the complexity is reduced. On the contrast, computational aesthetics based on inputting constrains and algorithms belongs to a bottom-up process which is established among huge amount of data and algorithm will deal with amazing complexity for us (Fig.16). Human and machine will collaborated with each other, and finally turn to symbiont. These tools can be very transformational, but they shouldn't be overhyped, and tools allow us to do very interesting things, but they're not magically going to solve all the problems for us, thus we

still need to be a good designer.



[Fig 16] Top-down & Bottom-up

7. Conclusion

This study was initiated from aesthetics and analyzed it from several perspectives as design, creativity, aesthetic value, sensation & perception and aesthetic codes in nature. We withdraw a basic imprint that it consists of aesthetic expression and aesthetic experience. In addition, computational aesthetics as a rising new aesthetics has evoked an echo of all design disciplines. This paper focuses on the research and analysis of aesthetics and computational aesthetics, which aim to explore the differentiation and correlation between them. In the background of the mass applying of computer aided design methods in famous architecture offices, it is necessary to probe how this design method changed designers' way of prototyping and thinking. Through the case study, three typical cases from architecture and AI are listed to draw a perspective that compared to simplicity as the presentation of modernism, amazing complexity of parametricism start a new era of design, while AI shows another possibility to understand design thinking and making. Generated by algorithms, computational aesthetics shows the rational and logical way to pursue new aesthetic experience, compared to the emotional thinking of traditional aesthetics. Computational aesthetics derived from generative system stands for rational mind to pursue algorithmic expression beyond human perception, with the resource of algorithms. As for computational aesthetics, several aspects such as algorithmic aesthetics, computational creativity and computational aesthetics assessment are analyzed to withdraw a multi-dimensional cognition of the bottom-up information programming process which is different from traditional aesthetics evoked by top-down thinking process via concept. Additionally, it should be aware that the differentiations in these interactive thinking processes determine the differentiation of the final expression. As for design, we could proposal one question such as: design is logical emotion or emotional logic? Likewise the discuss between humanized aesthetics and computational aesthetics is also such a thing.

The limitation of this research is that although this paper pointed the design processing based on two different types of aesthetic styles, it does not involve the discussion on issues about AI. For the next phase of this research area, a comprehensive study around AI design with more specific questions will be studied further, for instance, will AI has the power to merge these two kinds of design processing models together? A new era of machine designing and making realized by AI system still worthy to be expected.

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