EXTENDING DESIGN COGNITION WITH COMPUTER VISION AND GENERATIVE DEEP LEARNING

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ABSTRACT

EXTENDING DESIGN COGNITION WITH COMPUTER VISION AND GENERATIVE DEEP LEARNING

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This thesis proposes to scrutinize the project of extending cognition in the field of design by providing the exploration of alternative procedures of formalization. It aims at investigating the possible extensions of design cognition with a theoretical framework based on the concept of Extended Cognition, traced within two different contexts: One is the phenomenological context, which aims at a sensual and cognitive extension in the design studies of the 20th century searching for a counter-cultural expression; the other is the naturalized context of Extended Cognition, now reconceptualized within the field and paradigm of the cognitive and computational sciences, away from its phenomenological antecedents. The thesis aims at bringing current cognitive and computer science advancements into the design theory by reconsidering the notion of Extended Cognition within a fully naturalized context, and to this aim, explores a methodology to consider and apply the underlying principles of Computer Vision and Generative Deep Learning methods. An interdisciplinary project is developed for testing the approach discussed in the thesis,

in which a 3-D point cloud model of a physical structure is produced by LiDAR scanner. Various experiments are carried out with this data, where the datasets created are processed by a Deep Generative Model to produce new 3-D models that are embodied in alternative formal representations such as point clouds, mesh models, and bounding boxes. The generated models are then used as a design vocabulary to produce alternative combinatorial formations that reflect the extensions of design cognition.

Keywords: Design Cognition, Point-cloud, Computer Vision, Deep Generative Models

ÖZ

BİLGİSAYAR GÖRÜŞÜ VE ÜRETKEN DERİN ÖĞRENME İLE TASARIM BİLİŞİNİ GENİŞLETMEK

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Bu tez, alternatif biçimselleştirme prosedürlerinin araştırılmasını sağlayarak, tasarım alanında bilişin genişletilmesi projesini incelemeyi önermektedir. İki farklı bağlamda, 20. yüzyıl fenomenolojik öncüllerinin karşı-kültürel ifade arayışında ve günümüzün bilişsel ve hesaplamalı bilimlerin alanı ve paradigması içinde yeniden kavramsallaştırılan Genişletilmiş Biliş kavramına dayalı teorik bir çerçeve ile tasarım bilişinin olası uzantılarını araştırmayı amaçlamaktadır. Tez, Genişletilmiş Biliş kavramını doğallaştırılmış bir bağlamda yeniden ele alarak mevcut bilişsel ve bilgisayar bilimi ilerlemelerinin tasarım alanındaki yansıma ve uyarlamalarını izlemeyi amaçlamaktadır ve bu amaçla Bilgisayarla Görme ve Üretken Derin Öğrenmenin temel ilkelerini uygulamak için bir metodoloji araştırmaktadır. Tezde tartışılan yaklaşımı test etmek için disiplinler arası bir proje geliştirilmiş ve LiDAR tarayıcı ile fiziksel bir yapının 3 boyutlu nokta bulutu modeli üretilmiştir. Bu verilerle, oluşturulan veri kümelerinin, nokta bulutları, ağ modelleri ve sınırlayıcı kutular gibi alternatif biçimsel temsillerde somutlaşan yeni 3-D modeller üretmek

için Derin Üretken Model tarafından işlendiği çeşitli deneyler yapılmıştır. Üretilen modellerin daha sonra tasarım bilgisinin uzantılarını yansıtan alternatif birleşimsel oluşumlar üretmek için bir tasarım sözlüğü olarak kullanılması amaçlanmıştır.

Anahtar Kelimeler: Tasarım Bilişi, Nokta bulutu, Bilgisayarla Görme, Derin Üretken Modeller



To my family,

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CHAPTER 1

INTRODUCTION

This thesis aims to explore possible extensions of design cognition by tracing the theoretical framework developed on the concept of Extended Cognition, which is a way of investigating the mind. Studies on mental processes in cognitive and computer sciences enable the exploration of alternative formalization procedures in design. The research scrutinizes such formal methods established with Computer Vision and Deep Generative Models. Naturalized in the contemporary computational paradigm, research on Extended Cognition is also traced in its antecedents in 20th century design studies that were then of a phenomenological and sensual nature. Coming to an end with the disappearance of the counterculture in which it flourished in the 20th century, research on Extended Cognition is scrutinized in current studies in under a naturalized cognitivist and computational context.

1.1 Research Problematic

The hypothesis of Extended Cognition developed by Clark and Chalmers[1] was introduced in the realm of the cognitive science as an alternative approach to studying the mind. However, nowadays, it is a well-established theory in cognitive science. The issue of searching for cognitive extensions of mental processes as

[1] Andy Clark and David Chalmers, "The Extended Mind," *Analysis* 58, no. 1 (1998): 7–19.

embodied from the human mind and extending to the physical world has recently come to occupy an important place in emerging cognitive science.[2] The design approach called Extended Cognition, Expanded Mind, or Extended Vision, manifested as the reflection of the counterculture movement of the 1960s and 1970s, was an understanding of architecture as a cognitive process that moves beyond the physical space.[3] [4] [5] In that period, operations on mental processes with ecstatic drugs and manipulation of the mind-external world relationship through some biological and chemical tools were investigated to extend design cognition.[6] [7]

In current studies in cognitive sciences, the extensions of cognition and vision in the outside world are examined in a naturalized way through the transformation, manipulation, and exploitation of external world structures.[8] In order to explore cognitive extensions, the developments in neuroscience, interdisciplinary vision science, and computer science propose making use of cognitive information in physical structures.[9] [10] Thus, it is predicted that a naturalization can be made through adding new layers to the use of Artificial Intelligence (AI) systems in design studies

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[2] Mark Rowlands, *The New Science of the Mind: From Extended Mind to Embodied Phenomenology* (Cambridge, Mass: MIT Press, 2010).
[3] Jim Burns, *ARTHROPODS: New Design Futures* (Academy Editions, 1972), https://search.ebscohost.com/login.aspx?direct=true&db=cat00040a&AN=bilk.171930&site=eds-live.
[4] Hans Hollein, "Alles Ist Architektur," 1968, https://monoskop.org/File:Hollein_Hans_et_al_Alles_ist_Architektur_Bau_1968.pdf.
[5] Andrew Ayers, "The Sublime Dystopian Visions of Superstudio," La Gazette Drouot, 2021, https://www.gazette-drouot.com/article/the-sublime-dystopian-visions-of-superstudio/21454.
[6] Eleonora De Crescenzo and Russel Duncan, "Ken Kesey and the Merry Pranksters -The Origins of the Psychedelic Movement Through the Lens of The Electric Kool-Aid Acid Test" (Europe and the United States in the Sixties, Berlin: Freie Univertät Berlin, 2011).
[7] Rodrigo Alonso, "Expanded Space | Art and Technology | Rodrigo Alonso," Expanded Space, 2004, http://www.roalonso.net/en/arte_y_tec/espacio_expandido.php.
[8] Rowlands, *The New Science of the Mind*.
[9] Clark and Chalmers, "The Extended Mind."
[10] Stephen E. Palmer, *Vision Science: Photons to Phenomenology* (Cambridge, Mass: MIT Press, 1999).

by the manipulation of cognitive information in physical structures.[11] Relating naturalization with research in the analytical-cognitive field, Zeynep Mennan notes that "naturalization accounts for an objectification of cognitive and spiritual processes expressed in an ever-growing accuracy of translation into formal languages." [12] This thesis is problematized in the context of naturalization that aims to bring this approach of cognitive sciences, which has a similar theme with the phenomenological design research in the previous century, to the current design cognition interface.

1.2 Aims

Research in the field of design cognition involves the objectification of cognitive processes in design, requiring the use of developments in neuroscience, computer science, and cognitive science. In this study, cognitive extensions in a design context are investigated by producing a project on the alternative representations transforming the cognitive information in the physical structure.

The hypothesis established in the context of this problematization asserts that it is possible to decode and use the cognitive information of an architectural object, which is an external world structure that carries the information about the cognitive processes, for investigating the extensions of design cognition. Referring to the Extended Cognition Hypothesis by Clark and Chalmers[13] stating that external world objects contain information about cognitive processes, a building, which is a part of

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[11] Keith Frankish and William Ramsey, eds., *The Cambridge Handbook of Cognitive Science* (Cambridge: Cambridge University Press, 2012).
[12] Zeynep Mennan, "Mind the Gap: Reconciling Formalism and Intuitionism in Computational Design Research," *Footprint* 8 (September 1, 2014): 33–42, https://doi.org/10.7480/footprint.8.2.810.
[13] Clark and Chalmers, "The Extended Mind."

the physical world, is experimented with its point cloud geometry produced with LiDAR Scanner. This data provides the coordinate of every single point of the building within its context, providing therefore for information of the external world. The point cloud and mesh model of the architectural structure are manipulated and transformed to produce datasets and to operate through information processing systems. By processing these datasets with Artificial Neural Networks, which is a simulated form of cognition having the ability to learn[14], the relationship between the cognitive processes and design (itself part of the external world) is experimented within a computational environment.

The thesis, therefore, scrutinizes the concept of Extended Cognition within the context of extensions to design cognition and puts the above hypothesis to test through the project that investigates ways of decoding the cognitive information embedded in the design context and its transformations via alternative representations. While investigating the hypothesis, this thesis aims to answer the following questions:

-What data types and representations of physical structure can be used for the analysis of the cognitive information contained within the structure?

-How should architectural structures be transformed while creating data sets in order to decode the cognitive information of designers in the physical world structures?

-What are the information processing models suitable for decoding the information of design cognition in physical structure?

[14] Jay Friedenberg and Gordon Silverman, *Cognitive Science: An Introduction to the Study of Mind* (Thousand Oaks, Calif: Sage Publications, 2006).

-How can information processing models designed with this approach be used in the production of alternative representations through the extension of design cognition?

1.3 Methodology

The Extended Mind/Cognition Hypothesis[15], which is an approach to studying the mind in cognitive sciences, and the way it is handled by different researchers are analyzed for investigating how physical structures could be processed to examine them as part of cognitive processes. The Extended Mind/Cognition Hypothesis developed by Andy Clark and David Chalmers claims that the mind is a "leaky organ" that infiltrates from within the head.[16] Based on this approach, Mark Rowlands argues that external world objects could be considered parts of cognitive processes when they are used for other mental tasks by being transformed, manipulated, and exploited through various hardware besides the human brain. [17] Depending on this understanding, which will be examined in detail in Chapter 2, this thesis establishes a theoretical framework for considering Extended Cognition in design studies. According to the approach of the thesis, physical architectural objects, which are a part of the external world and which carry the conscious design decisions of the architect, could be used with its sensory data directly obtained for the physical environment.[18] This data can be manipulated and transformed to be processed and used for further cognitive tasks in information processing systems according to specific strategies reflecting the conscious design decisions.[19] To define the strategies about processing the external world data to explore possible extensions

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[15] Clark and Chalmers, "The Extended Mind."
[16] Clark and Chalmers.
[17] Rowlands, *The New Science of the Mind*.
[18] See the Project in chapter 4
[19] See the Project in chapter 4

of design cognition, the thesis first examines the underlying strategies of Computer Vision in Chapter 3. In this way, it is aimed to consider Extended Cognition within a systematic approach based on the computational approach to vision by David Marr,[20] which is fundamental and partly the founder of classical cognitive science shaping subsequent research.[21]

According to Marr's approach, visual perception, which is a cognitive task, can be explained by input-output transformations in multiple stages that gradually reflect the components of the object.[22] This understanding of Marr is called the "Tri-Level Hypothesis" of information processing[23], which will be discussed in detail in Chapter 3 by handling as a general framework for explicitly processing design data to be used in Extended Cognition research. Inferring from Marr's multi-level analysis of vision and information processing, the design data is transformed and manipulated in stages, reflecting the design references and part-whole relationships by various experiments in the project in Chapter 4. Then, to determine which information processing tool could be appropriate for processing design data in Extended Cognition research, the Artificial Neural Networks (ANNs), which is the most recent development in computer vision simulations,[24] is discussed.[25] ANNs are behavior-based models of Artificial Intelligence (AI) that are designed according to the strategies related to inputs and outputs instead of predefined theories and certain rules of knowledge-based AI.[26] Therefore, the use of ANNs, which is a simulated form of cognition, having a behavioral and brain-like nature, containing uncertainty

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[20] David Marr, *Vision: A Computational Investigation into the Human Representation and Processing of Visual Information* (Cambridge, Mass: MIT Press, 2010).
[21] Rowlands, *The New Science of the Mind*.
[22] Marr, *Vision*.
[23] Michael Dawson, *Understanding Cognitive Science* (Malden, Mass: Blackwell, 1998).
[24] Palmer, *Vision Science*.
[25] See chapter 3
[26] Friedenberg and Silverman, *Cognitive Science*.

and specific strategies on input-output transformations[27], is considered to be suitable for Extended Cognition research. This thesis also seeks a generation task aiming to explore possible extensions of design cognition. Hence, Deep Generative models proposed by the advancements in ANNs to transform the data and generate new samples from them is investigated by discussing the methodologies used in current design studies in Chapter 3. Finally, the interdisciplinary project developed, corresponding to and illustrating the theoretical approach and methodology of the thesis, is demonstrated in Chapter 4.

1.4 Structure of the Thesis

As mentioned previously, the thesis traces the notion of Extended Cognition in two different contexts, the phenomenological and the naturalized. In Chapter 2, firstly, the naturalized idea of Extended Cognition is discussed, which was pursued in its phenomenological form in the 20th century in design, and then re-emerging as an alternative approach to analyzing the mind in Cognitive Science after a few decades. According to the Extended Cognition Hypothesis,[28] the external world structures, which are formed as a result of cognitive activity and therefore carry cognitive information, are partially parts of cognitive processes as extensions of human cognition. Thus, it is possible to draw inferences about cognition through manipulation and analysis of external world structures as an alternative to the approaches involving symbolic representations or modeling of neural circuits inside the brain for the realization of cognitive processes in artificial systems.[29] The approach of considering Extended Cognition as formalized within the computational

[27] Friedenberg and Silverman.
[28] Clark and Chalmers, "The Extended Mind."
[29] Andy Clark, *Supersizing the Mind: Embodiment, Action, and Cognitive Extension*, Philosophy of Mind (Oxford ; New York: Oxford University Press, 2011).

paradigm of design is discussed in the first sections of Chapter 2 by providing the theoretical approach of this thesis. Chapter 2 further discusses the concepts of the Extended Mind, Expanded Vision, or Extended Cognition that were emphasized by the counterculture movement of the 1960s and 1970s in the field of architecture and design. These concepts emerged with the search for an alternative field of cognition that started with the view of cognition as an escape from the monotonous and restrictive living conditions of the real world.[30] [31] The pioneers of the period following this trend did various alternative design experiments that considered architecture as a non-physical, cognitive process.[32] In these experiments making use of chemical and biological catalyzers to stimulate the mind, designers pursued alternative cognitive domains of architecture, which are supposed to be achieved by extending cognition and vision. These experiments, which provide for the manipulation of the relationship between the human, physical world, and perception of time, aim to investigate and change the interaction of the mind and the external world by exploring sensual and cognitive extensions of the mind.

In Chapter 3, the underlying principles of Computer Vision and Deep Learning methods are investigated by discussing the current methodologies used in design studies. Although the idea of Extended Cognition proposes an alternative conceptual framework for cognitive processes that go beyond the mind, it does not reject the symbolic and representational methods.[33] In fact, the most natural way to explore cognitive extensions through the transformation and manipulation of external world structures might be the information processing-based systems of cognitive science such as Artificial Neural Networks (ANNs). Chapter 3 firstly examines the

[30] Ayers, "The Sublime Dystopian Visions of Superstudio."
[31] Hollein, "Alles Ist Architektur."
[32] Burns, *ARTHROPODS*.
[33] Frankish and Ramsey, *The Cambridge Handbook of Cognitive Science*.

computational approach of information processing and vision developed by David Marr to determine a strategy for transforming the design data. According to the multi-level analysis of Marr to represent the objects for mental tasks, the thesis develops an understanding of transforming the data of physical world structures in stages. These transformation stages, according to the design references and volumetric relations, are then tested in the project in the next chapter. In Chapter 3, the behavior-based and brain-like nature of ANNs that make them appropriate to be used for processing design data to generate extensions of design cognition is explored. Chapter 3 then discusses the Deep Generative models, which is the most recent development in ANNs because the aim of the thesis is to explore extensions of design cognition includes a generation task. The state-of-the-art Generative Models are finally demonstrated by discussing the methodologies used in current design studies.

In Chapter 4, in the interdisciplinary project, the thesis explores the situation where architecture belonging to the outside world reflects the cognitive activity of the architect. It is assumed that the architect's design cognition can be extended at a human-machine interface while generating alternative representations of the physical world through Artificial Neural Networks (ANNs) trained with real-world data of architecture. In the project developed to test the hypothesis, a detailed 3-D point cloud model is created by scanning a complex architectural structure, the Faculty of Architecture at METU, with LiDAR. The point cloud data of the building, produced at the Photogrammetry Laboratory of the Faculty of Architecture, METU and mesh models are divided into pieces according to architectural references and part-whole relationships reflecting the conscious design decisions with various techniques, and datasets are created. A 3-D Deep Generative Model is then designed using these datasets, and new 3-D models produced by Artificial Intelligence are examined. These new 3-D models, which are embodied in different representations,

are used as a design vocabulary, and new combinatorial formations are generated to explore possible extensions of design cognition.

CHAPTER 2

EXTENDED COGNITION IN COGNITIVE SYSTEMS AND DESIGN

As explained in the Introduction, the present research aims at the exploration of possible extensions and alternative representations of design cognition: To this end, it scrutinizes the cognitive information encoded in physical world structures as they are decoded by various information processing methods. In this chapter, the idea of Extended Cognition, which is an approach to understanding the mind in cognitive sciences, is examined as the theoretical framework used in research. This chapter also examines and entails a discussion of 20th century architectural experiments and studies in relation to the concept of Extended Cognition. Currently, Extended Cognition, a subject matter of interdisciplinary studies, has been mostly re-appropriated in the field of cognitive sciences. It seems, therefore, relevant to examine the early examples forming a first instance of this discussion in design studies while handling the interdisciplinary advancements for Extended Cognition research.

2.1 Studying the Mind through an Alternative Approach

> If we are to understand mind as a locus of intelligence, we cannot follow Descartes in regarding it as separable in principle from the body and the world…Broader approaches, freed of that prejudicial commitment, can look again at perception and action, at skilful involvement with public equipment and social organization, and see not principled separation but

> all sorts of close coupling and functional unity…Mind, therefore, is not incidentally, but intimately embodied and intimately embedded in its world. - Haugeland[34]

Mental activities such as perception, thinking, and learning that people perform in interaction with the body and the external world make it undeniable that the mind has a deep and crucial relationship with the body and the world.[35] This cyclical relationship of mind, body, and world leads to an approach of the mechanism of the mind being extended to the world; that is, some aspects of human thinking are extended through the construction of extended cognitive circuits that are the material foundations of cognition.[36] The notion of Extended Cognition has evolved as an alternative approach to the classical and connectionist methods of studying the mind in cognitive science. In order to perceive the way of thinking provided by Extended Cognition, it would be beneficial to discuss the approaches to the mind by comparing them with this alternative approach.

In early approaches to the study of the mind, it is believed that mental processes such as perception and thinking occur only through brain processes or are equivalent to brain processes.[37] With the development of cognitive science, the brain has begun to be considered as hardware that enables the realization of mental processes and mental processes as programs that run on the hardware.[38] This classical approach in cognitive science aims to describe the programs and explain their functioning in the brain by considering mental processes as abstract programs.[39] In the classical approach, the focus

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[34] John Haugeland, *Having Thought : Essays in the Metaphysics of Mind* (Harvard University Press, 1998).
[35] Clark, *Supersizing the Mind*.
[36] Clark.
[37] Rowlands, *The New Science of the Mind*.
[38] Rowlands.
[39] Rowlands.

was on producing programs, that is, cognitive software, for the purpose of making symbolic descriptions of cognitive processes.[40] On the other hand, in the connectionist approach developed in the 1980s, it was aimed to understand mental processes by focusing on hardware, producing realistic models of the neural architecture that underlies cognitive processes.[41] Artificial Neural Network models produced for this purpose resemble hardware in which neural circuits in the brain are simplified and explicitly modeled for mental processing tasks.

The approaches to understanding the mind are based on the neural functioning of the mind in the brain and central nervous system.[42] According to these approaches, various mental activities such as perception, thinking, and learning are analyzed and explained through their symbolic representations in the brain or the models of the neural circuits that provide them.[43] The common feature of these approaches, which include symbolic representations, and the connectionist approach, which is based on patterns of neural activity, is that both are related to processes inside the head of the cognizing organisms[44]. Cognitive processes, that is, mental processes considered in cognitive science, are ultimately brain processes or functional operations of the brain and take place inside the thinking organism.

In the Extended Cognition approach, cognitive processes are described not as a result of input-output transformation within the brain but as the interaction of cognition with its local mechanisms through its nature infiltrating the body and the world.[45] The Extended Cognition is the idea that mental events depend, without any means, directly on the external environment of the organism; that is, local systems of the mind are not

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[40] Rowlands.
[41] Rowlands.
[42] Clark, *Supersizing the Mind*.
[43] Clark.
[44] Rowlands, *The New Science of the Mind*.
[45] Frankish and Ramsey, *The Cambridge Handbook of Cognitive Science*.

limited to being inside the head, but cognition infiltrates the body and the world.[46] This understanding includes real-world operations that partially perform cognitive processes and loops that randomly transcend the boundaries of the brain, body, and world, provided by feedback and feed-forward relationships with the external world.[47] Andy Clark (2008) expressed the situation where non-biological, external world processes take part as a part of cognitive processes in cooperation with humans and change the boundaries of the mind and the world as follows:

> External and nonbiological information-processing resources are also apt for temporary or long-term recruitment and incorporation rather than simply knowledge-based use. To whatever extent this holds, we are not just bodily rind sensorily but also cognitively permeable agents.[48] (see Clark 1997[49]; Clark and Chalmers 1998[50]).

This way of thinking about the mind is based on the combinations of ideas that mental processes are embodied, embedded, enacted, and extended instead of brain processes or functional procedures in the brain.[51] Embodiment is the idea that mental processes originate from external and larger bodily structures and processes.[52] Embeddedness is based on the understanding that mental processes are designed only to work in conjunction with an environment outside the brain, and therefore mental processes cannot function properly without a necessary environment.[53] The notion of enactedness is that mental processes are formed not only from the operation of neural circuits but also from

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[46] Clark, *Supersizing the Mind*.
[47] Clark.
[48] Clark.
[49] Andy Clark, *Being There: Putting Brain, Body, and World Together Again* (Cambridge, Mass: MIT Press, 1998).
[50] Clark and Chalmers, "The Extended Mind."
[51] Rowlands, *The New Science of the Mind*.
[52] Rowlands.
[53] Rowlands.

the general activities of the thinking organism, that is, from its activity in the world and the world's response to this activity.[54] And extendedness is the approach that mental processes do not only take place exclusively in the human head but extend to the outside world in various forms.[55]

The approaches in cognitive science are used to deal with symbolic representations or neural circuits as mind-specific tools for analyzing mental activities.[56] On the other hand, Extended Cognition approach reveals that not only the brain but also other physical tools that contain cognitive information, the body, and the world play a role in the formation of cognitive processes.

2.2 The Extended Cognition/Mind Hypothesis

> It may be that the biological brain has in fact evolved and matured in ways which factor in the reliable presence of a manipulable external environment. It certainly seems that evolution has favored on-board capacities which are especially geared to parasitizing the local environment so as to reduce memory load, and even to transform the nature of the computational problems themselves. Our visual systems have evolved to rely on their environment in various ways... they take advantage of the computational shortcuts afforded by bodily motion and locomotion. Perhaps there are other cases where evolution has found it advantageous to exploit the possibility of the environment being in the cognitive loop. -Clark & Chalmers[57]

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[54] Rowlands.
[55] Rowlands.
[56] Frankish and Ramsey, *The Cambridge Handbook of Cognitive Science*.
[57] Clark and Chalmers, "The Extended Mind."

The Extended Cognition approach is based on the interpretation of holding and accessing a large amount of information provided by the developing technology as the extension of cognition to the outside world, that is, assuming the inventions in the outside world as elements of cognition.[58] Clark and Chalmers[59] argue that the environment plays an important role in the formation of cognitive processes and that the brain develops under the influence of cognitive extensions in the external world surrounding the body.[60]

The Extended Cognition/Mind Hypothesis[61], developed by Clark and Chalmers, claims that it is not possible to separate the mind and its information processing from the world.[62] According to the Extended Cognition approach, the fact that information processing is in the functioning of both the world and the brain leads to the blurring of the boundary between the mind and the world and ensures an interaction between them.[63] Thus, the mental processes of humans may be partially carried out by processes and structures outside the mind. That is, the mind extends beyond the boundaries of the body through cognitive processes based on various external supports.[64]

Contrary to classical approaches, which assume that thinking is entirely within the body and that the external world is represented in the mind through perception, the Extended Cognition Hypothesis argues that cognition is "scaffolded."[65] Andy Clark (1997), who defined the mind as a "leaky organ" that spreads from within the head

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[58] Carolyn Panzer Sobel and Paul Li, *The Cognitive Sciences: An Interdisciplinary Approach*, Second edition (Thousand Oaks: SAGE Publications, 2013).
[59] Clark and Chalmers, "The Extended Mind."
[60] Sobel and Li, *The Cognitive Sciences*.
[61] Clark and Chalmers, "The Extended Mind."
[62] Michael R. W. Dawson, *Mind, Body, World : Foundations of Cognitive Science*, Open Textbook Library. (Minneapolis, MN: Open Textbook Library, 2013).
[63] Dawson.
[64] Clark, *Supersizing the Mind*.
[65] Dawson, *Mind, Body, World*.

by containing the external scaffold, expressed this approach in line with the Extended Cognition Hypothesis with the following words: "It is the human brain plus these chunks of external scaffolding that finally constitutes the smart, rational inference engine we call mind."[66]

Based on the Extended Cognition Hypothesis, Mark Rowlands (2010) argues that the world is an external store of information related to hybrid cognitive processes consisting of both internal and external operations like reasoning, perceiving, remembering.[67] While external operations are actions such as the use, manipulation, and transformation of physical structures that carry information about cognitive processes, internal processes give the organism the ability to transform and use the structures of the external world.[68] Clark and Chalmers (1998) explain that in order to define the material tools of cognitive processes, attention should be paid to the functional and computational organization of the whole process, ignoring the traditional boundaries of the skin and skull:[69]

> "If, as we confront some task, a part of the world functions as a process which, were it to go on in the head, we would have no hesitation in accepting as part of the cognitive process, then that part of the world is (for that time) part of the cognitive process." - Clark and Chalmers[70]

However, the Extended Cognition Hypothesis does not make a direct claim about cognitive processes.[71] This thesis argues that some cognitive processes consist, in part, of

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[66] Clark, *Being There*.
[67] Rowlands, *The New Science of the Mind*.
[68] Rowlands.
[69] Andy Clark, *Mindware: An Introduction to the Philosophy of Cognitivescience*, Second Edition (New York: Oxford University Press, 2013).
[70] Clark and Chalmers, "The Extended Mind."
[71] Rowlands, *The New Science of the Mind*.

the transformation, manipulation, and exploitation of physical structures.[72] This approach claims that the manipulation of external world structures is part of cognitive processes, but it does not mean that they are identical with cognitive stages.[73] These structures thus become part of the cognitive process only when they are in the process of being transformed or manipulated.[74]

According to Rowlands, some mental processes spread to the environment of the thinking organism and thus occur through the actions of the organism in the external world.[75] The actions of the cognizing organism in the external world are to manipulate, transform or exploit the physical structures that are formed as a result of the fulfillment of a certain cognitive task and therefore carry information about the cognitive process.[76] The organism, through its actions on these structures, transforms the cognitive information found in the structures of the external world into information ready to be used in organisms and other cognitive operations.[77] According to the Extended Cognition Hypothesis, therefore, some cognitive processes are partially formed by the use, manipulation, or transformation of external structures that carry information about the cognitive processes of the thinking organism.

This research aims to question whether material architecture encoding the cognitive information about design can be explored through Artificial Neural Networks: In other words, it scrutinizes the idea of searching for an alternative cognitive domain in design. This idea is a thematic pursuit in architecture that has found its cultural and artistic manifestations in the 1960s. These can be considered as historical

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[72] Rowlands.
[73] Rowlands.
[74] Rowlands.
[75] Rowlands.
[76] Rowlands.
[77] Rowlands.

antecedents to the hypothesis of Extended Cognition, an early research track in the field, which after a long break, has found itself re-appropriated today, fostered mainly by cognitive and computational sciences.

2.3 Exploration of the Brain through Ecstatic Drugs

Sigmund Freud[78] conducted several scientific experiments to find the enigmatic aspects of consciousness.[79] Freud used to give great importance to the use of drugs, especially cocaine, for this purpose, so he wrote his famous book Über Coca (1885).[80] In the 1960s, an alternative culture emerged, where various experimentations with sensations were used as tools to release the stereotypes of former representations.[81] The "Summer of Love" (Figure 2.1 (left)) hereby occurred as a specific spiritual occasion in California: It was a great collective party with shows and music, and a new drug called Acid was distributed to people there.[82] The main band of that period was the Grateful Dead. Their music felt the same as the influence of LSD, which is a drug developed by Albert Hofmann (Figure 2.1 (right)).[83]

[78] Sigmund Freud and James Strachey, *The Standard Edition of the Complete Psychological Works of Sigmund Freud* (London: Hogarth Press and the Institute of Psycho-Analysis, 1955).
[79] Sigmund Freud and Joan Riviere, *A General Introduction to Psychoanalysis. Authorized English Translation of the Rev. Ed. by Joan Riviere, with Prefaces by Ernest Jones and G. Stanley Hall*, Washington Square Press Book W599 (New York: Wordsworth Editions, 2012).
[80] Sigmund Freud, *Über Coca* (M. Perles, 1885).
[81] Gene Anthony and Michael McClure, *The Summer of Love: Haight-Ashbury at Its Highest* (San Francisco, Calif.: Last Gasp, 1995).
[82] Anthony and McClure.
[83] Anthony and McClure.



Figure 2.1 : (Left) The Summer of Love, 1967; (right) Albert Hoffman in lab.

Source: (Left) "The Hippie Spirit Lives in San Fran 50 Years On". Web. 12 June 2021. <**https://www.qantas.com/travelinsider/en/explore/north-america/usa/san-francisco/summer-of-love-50-year-anniversary-in-san-francisco.html**>. (Right) "The Swiss beginnings of LSD" Web. 12 June 2021. <**https://houseofswitzerland.org/swissstories/history/swiss-beginnings-lsd**>.

This collective movement of an alternative consciousness was an escape from reality and rationality in the 1950s and 1960s. In the 1960s, what is called a "psychedelic experience" emerged to explore new styles of life and thought in the United States.[84] In this way, extraordinary experiments have been done on the brain and psyche using drugs, aiming to find the enigmatic aspects of human perception.[85] The interaction of psychotropic substances with the human mind began to be researched by successful psychologists such as Timothy Leary and Richard Alpert at Harvard University in 1960[86] , who developed the Harvard Psilocybin Project. Psilocybin, an

[84] Anthony and McClure.
[85] Anthony and McClure.
[86] "Timothy Leary," accessed December 23, 2021, https://psychology.fas.harvard.edu/people/timothy-leary.

entheogenic hallucinogen, is a substance that can be obtained naturally from some types of mushrooms.[87] To investigate the interaction of psilocybin with consciousness, Leary and Alpert applied it to volunteers and documented their real-time explanations.[88] LSD and psilocybin were not illegal in the United States at the time of these experiments.[89] After a while, the Harvard Psilocybin Project ended abruptly, and Leary and Alpert were fired from the university for distributing drugs to the students.[90] However, Timothy Leary turned out to be the icon of that period, of a counterculture and psychedelic drugs[91], making quite a number of publications in the Psychedelic Review magazine (1963-1971)[92]. Psychedelic Review (Figure 2.2) was not related to counterculture but was rather a scientific publication aiming to investigate the enigmatic nature of the brain through mind-altering drugs in the world of psychedelia.[93]



[87] "Timothy Leary."
[88] "Timothy Leary."
[89] Jay Stevens, *Storming Heaven: LSD and the American Dream* (Grove Press, 1987).
[90] "Timothy Leary."
[91] "Timothy Leary."
[92] "Psychedelic Review Archives 1963-1971," Multidisciplinary Association for Psychedelic Studies - MAPS, November 14, 2007, https://maps.org/2007/11/13/psychedelic-review-archive/.
[93] "Psychedelic Review Archives 1963-1971."

Figure 2.2: Psychedelic Review, Vol. I, No. 1, No. 6, No. 7, 1963-1971. Source: "Psychedelic Review Archives 1963-1971". Web. 12 June 2021. <**https://maps.org/2007/11/13/psychedelic-review-archive/**>

In that period, scientific experiments with the use of hallucinogenic drugs in this magazine led to the formation of a new culture, coming across with the hippie counterculture, which is the psychedelic movement. Bases of this movement depend on the experiences of Ken Kesey and his group of friends, the Merry Pranksters using LSD.[94] Pranksters occupied an important role in raising the awareness of LSD in society and drawing attention to its mind-expanding features, generating the psychedelic movement. The long-standing idea of Kesey, which was a distinguishing concept of the 1960s, is the foundation of the notion of freedom in mind and body.

2.4 The Notion of Expanded Mind: Extension of Vision through Expanded Arts and Cinema

During the late 1960s, the influence of drugs on perception has been tried to be reached through alternative methods that could mimic the experience of taking drugs. One of these methods is the shows that affect the cognitive activities of the audience with physical stimuli such as music and light (Figure 2.3). In 1966, Timothy Leary organized a multimedia show called "The Death of the Mind": University campuses were toured with this artistic performance that promised to keep the LSD effect alive.[95] Leary's works led to the formation of an organization called League for Spiritual Discovery (LSD). This spiritual community advocated the use of lysergic

[94] De Crescenzo and Duncan, "Ken Kesey and the Merry Pranksters -The Origins of the Psychedelic Movement Through the Lens of The Electric Kool-Aid Acid Test."
[95] Jim Chevallier, "Tim Leary and Ovum - A Visit to Castalia with Ovum," Jim Chevallier's Web Site, March 3, 2003, http://www.jimcheval.com/ovum/castalia2.html.

acid diethylamide (LSD) for purposes such as insight and meditation.[96] This show trend with music, light, and drugs, i.e., psychedelic shows spread all over the world from Europe to Japan, contributed to the formation of a counterculture.[97] They were psychedelic presentations, including demonstrations and drugs, expanding consciousness, and exploring the perception of space-time.



Figure 2.3 : (Left) Joshua Light Show; (right) Light Show at Whitney Museum. Source: (Left) "The Process of Illumination, Joshua Light show enhances Frank Zappa". Web. 12 June 2021. <**https://relix.com/articles/detail/the_process_of_illumination/**>. (Right) "Art-Headlights-Light Show At Whitney Museum, New York City" Web. 12 June 2021. < **https://artsandculture.google.com/asset/art-headlights-light-show-at-whitney-museum-new-york-city-also-jefferson-airplane-vocal-group/cwHLtyztUFEWpQ**>.

The conscious-expanding effect of media and arts on the reality of the external world is discussed in a book by Gene Youngblood called "Expanded Cinema."[98] A search for an alternative consciousness and lifestyle, Expanded Cinema, is an experiment in observing mind formations considering the films as extensions of consciousness.[99] What is meant by the term "expanded cinema" is the expanded consciousness; that

[96] Nina Graboi, *One Foot in the Future: A Woman's Spiritual Journey* (Aerial Press, 1991).
[97] Anthony and McClure, *The Summer of Love*.
[98] Gene Youngblood, *Expanded Cinema : Fiftieth Anniversary Edition*, Meaning Systems (New York, NY: Fordham University Press, 2020).
[99] Youngblood.

is, it aims to witness the consciousness of the human being reflected outside the mind through the eyes.[100] In this context, multi-media networks are actually intended to work as a nervous system.[101] The photographic images make it possible to interpret the external world without the necessity of verbal explanations through expanding vision and consciousness.[102] The cinematic reality, thanks to its illusory nature, provides an alternative metaphysical perception of time and space by extending the vision.[103]

The notion of expanded mind, which emerged with mind-expanding drugs, music, and light shows, brought along the extension of vision with psychedelic art. The reason light shows were so important in psychedelic art is that one of the most common effects of drugs is intense visions of light.[104] USCO, a group of filmmakers, poets, and artists, have used various lighting arrangements in their artwork.[105] They displayed a plastic eye that creates a hypnotic effect on the audience with the light reflected from it in their show in New York. The slow movement of the gels in the eye with the effect of the light inside aimed to reduce the viewer's perception of time (Figure 2.4 (left)).[106] Another artist, Richard Aldercoft, used a translucent hemispherical goggle that blocked binocular vision in a vision-based psychedelic experiment (Figure 2.4 (right)).[107] The images are produced by a kaleidoscopic machine that Aldercoft calls the Infinity Projector.[108] Patterns of light reflected from the machine unexpectedly attack the viewer's field of view.[109] Disorientation, which

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[100] Youngblood.
[101] Youngblood.
[102] Youngblood.
[103] Youngblood.
[104] "Psychedelic Art, Hallucinogenic Drugs and LSD Art," *LIFE*, September 9, 1966.
[105] "Psychedelic Art, LIFE."
[106] "Psychedelic Art, LIFE."
[107] "Psychedelic Art, LIFE."
[108] "Psychedelic Art, LIFE."
[109] "Psychedelic Art, LIFE."

is the basis of the psychedelic experience, is achieved in this experiment by distorting the perception of time and space.[110]

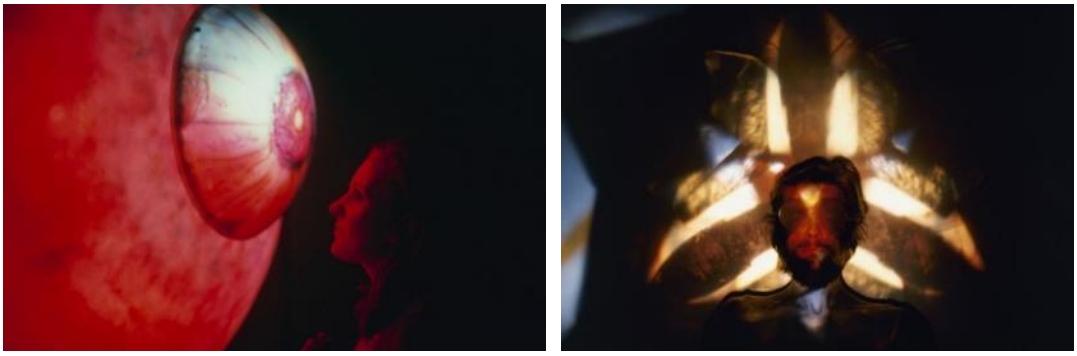


Figure 2.4 : (Left) Mesmerizing Eye: Fluctuating lights enflame a hypnotic plastic "eye"; (right) A vision-based psychedelic experiment. Source: (Left) Web. 12 June 2021. < https://www.trippingly.net/lsd-studies/2018/6/11/lsd-art-from-life-magazine-1966>. (Right) Web. 12 June 2021. <https://www.trippingly.net/lsd-studies/2018/6/11/lsd-art-from-life-magazine-1966>.

By electronically controlling light reflections, Gustav Metzger projected a color-changing heated fluid crystal onto the walls, thus producing a new environment adaptable to meditation and various events.[111] American filmmaker Jud Yalkut's work, Us Down By The Riverside (1966) (Figure 2.5 (left)), is another psychedelic show in which acid visuals are displayed accompanied by The Beatles' recording of Tomorrow Never Knows.[112] Along with Gene Youngblood, the author of Expanded Cinema (1970), which guided the progress of the concept of expanded mind with the advanced use of multimedia tools, another person who contributed this concept of

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[110] "Psychedelic Art, LIFE."
[111] "Liquid Crystal Slide Projections 1965/1998," *The Lancet* 352, no. 9137 (October 24, 1998): 1396, https://doi.org/10.1016/S0140-6736(05)60803-3.
[112] John Coulthart, "Us Down By The Riverside, a Film by Jud Yalkut," *{ Feuilleton }* (blog), October 10, 2015, http://www.johncoulthart.com/feuilleton/2015/10/10/us-down-by-the-riverside-a-film-by-jud-yalkut/.

extension of cognition is Aldo Tambellini. In 1967, avant-garde video artist Tambelli who was obsessed with the color black, said the following:

> "Black to me is like a beginning. Black gets rid of the historical definition. Black is a state of being blind and more aware. Black is a oneness with birth. Black is within totality, the oneness of all. Black is the expansion of consciousness in all directions."[113]

An example of Tambellini's avant-garde multimedia work is Black Trip (1965) (Figure 2.5 (right)). This work is a flickering black and white short film mixing, which consists of visual noise made by painting directly on the negative, accompanied by headache-inducing music.[114]

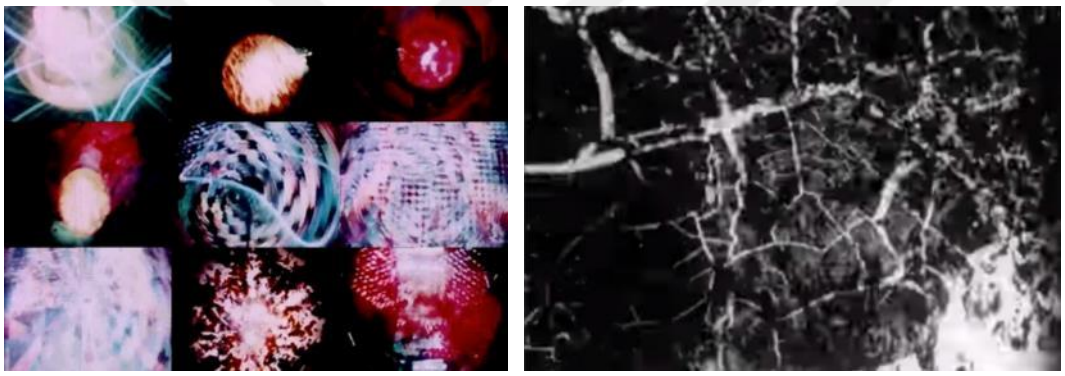


Figure 2.5 : (Left) Jud Yalkut, Us Down By The Riverside; (right) Tambellini, Black Trip. Source: (Left) Web. 12 June 2021. <http://www.johncoulthart.com/feuilleton/2015/10/10/us-down-by-the-riverside-a-film-by-jud-yalkut/>. (Right) Web. 12 June 2021. <https://www.youtube.com/watch?v=MQMBlV9tUnk >.

[113] Oliver Basciano, "Aldo Tambellini Obituary," *The Guardian*, November 29, 2020, sec. Art and design, https://www.theguardian.com/artanddesign/2020/nov/29/aldo-tambellini-obituary.
[114] Basciano.

2.5 Altered Perception of the Space for Extended Cognition

During the 1960s, some avant-garde architects and designers made productions that followed the idea of mind expansion.[115] Helmets were primarily used in these experiments of alternative spatial perception ideas to expand consciousness and the notion of reality. They were later replaced by experiments about the complete field with a holistic approach.

Haus-Rucker-Co was founded in Vienna in 1967 by Zamp Kelp, Klaus Pinter, and Laurids Ortner.[116] The group Haus-Rucker-Co in Vienna aimed to extend the spatial perception with a helmet in their Mind Expander (1967-96).[117] Mind-Expander (Figure 2.6 (left)) is a design in which two people experience various stages of consciousness with the red and blue lines in the balloon surrounding them.[118] It is a perception of an environment that two people discover by being together and alone.[119] Haus-Rucker-Co's Flyhead (Figure 2.6 (right)) is a complete environmental change designed for one person, allowing one to perceive the physical world and reality with different colors, sizes, and dimensions.[120] As an architectonic alternative to psychotropic drugs, the aim of Flyhead is to perceive different representations of reality by manipulating the perception of the physical environment.[121] The works of Haus-Rucker-Co are based on the study of the relationship between the body and the outside world by expanding the cognitive field.[122] Zamp Kelp, one of the founding members of the group, expressed this

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[115] Alonso, "Expanded Space | Art and Technology | Rodrigo Alonso."
[116] Elvia Wilk, "Space Invaders," *Frieze*, February 19, 2015, https://www.frieze.com/article/space-invaders.
[117] Alonso, "Expanded Space | Art and Technology | Rodrigo Alonso."
[118] Burns, *ARTHROPODS*.
[119] Burns.
[120] Burns.
[121] Wilk, "Space Invaders."
[122] Wilk.

understanding in an interview in 2014: “We wanted to expand consciousness not by drugs but rather by new, unprecedented spaces, objects, and utilities.” - Kelp[123]

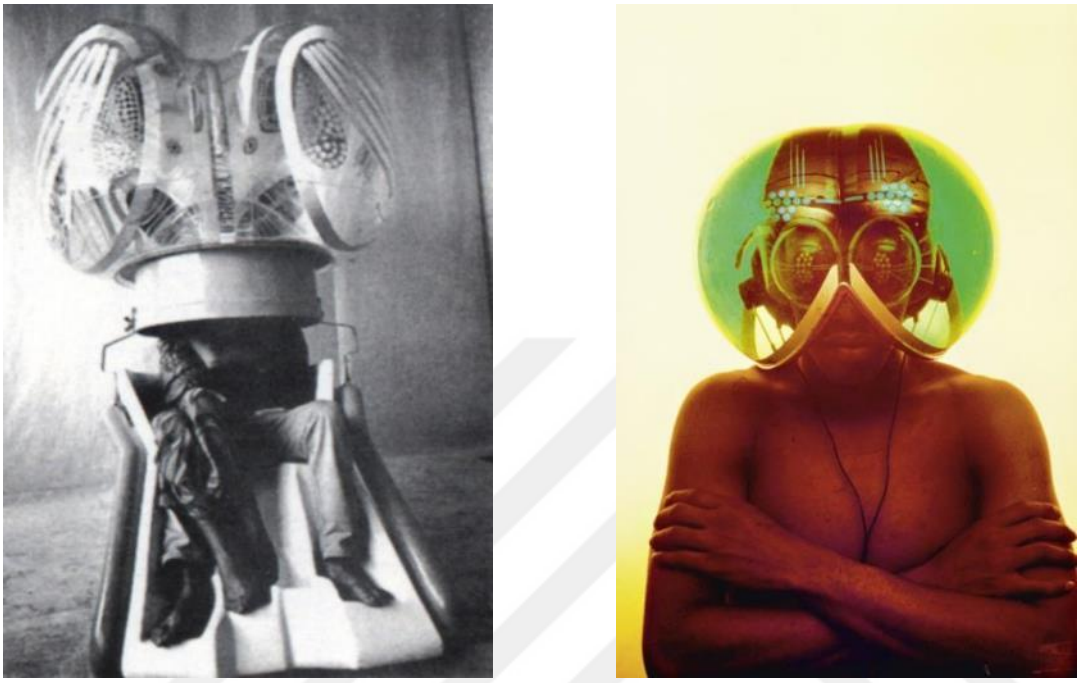


Figure 2.6 : (Left) Haus-Rucker-Co, Mind Expander; (right) Haus-Rucker-Co, Flyhead. Source: (Left) “Expanded space.” Web. 20 June 2021. <**http://www.roalonso.net/en/arte_y_tec/espacio_expandido.php**>. (Right) “Environment Transformer, Haus Rucker Co” Web. 20 June 2021. <**https://www.zamp-kelp.com/environment-transformer/** >.

Austrian artist and architect Walter Pichler was a visionary who felt the constraints of traditional aspects of architecture. Instead of structural configurations, Pichler designed by associating media and technology with space and perception.[124] The TV

[123] Wilk.
[124] Artdaily, “Grand Retrospective Surveying the Work of Walter Pichler Spanning Five Decades Opens in Salzburg,” accessed December 24, 2021, https://artdaily.cc/news/91955/Grand-

Helmet (Figure 2.7 (left)) designed by Pichler in 1967 immersed the user in an endless network of information, disconnected from the external world.[125] The artist reflects his thinking of the phenomenal and perceptual beyond the physical space through this work.

Brazilian artist and passionate writer Lygia Clark is one of those artists interested in the relationship between the mind and the outside world.[126] Dialogue: Google (Figure 2.7 (right)), designed by Clark in 1968, is a tool that changes perception. This design, reminiscent of the gas masks of World War I, changes the vision of the participant, allowing the interpretation of the acts of being and seeing.[127]

Clark refers to the inability of gestalt psychology to explain the phenomenon of analyzing the causal reality of space and form through time and spatialization.[128] She hence pursues the space-time relation by investigating the phenomenon of reality being the sum of all actions and the time being the action in the process of realization.[129] Clark believes that the perception of the body and reality can be transformed without having a physiology or form.[130] Referring to the overwhelming effect of architectural space, she explains the feeling of being independent by the

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retrospective-surveying-the-work-of-Walter-Pichler-spanning-five-decades-opens-in-Salzburg#.YO_A9egzbcs%20%20Retrieved%202021-06-05.

[125] Art Selectronic, "Virtual Worlds: Walter Pichler's Futuristic Visions | ART SELECTRONIC," 2013, https://artselectronic.wordpress.com/2013/02/04/virtual-worlds-walter-pichlers-futurist-visions/.

[126] Lygia Clark and Yve-Alain Bois, "Nostalgia of the Body," *October* 69 (1994): 85–109, https://doi.org/10.2307/778990.

[127] Evie Ward, "Fashion Is a Technology of Communication: The Intimacy of Accessory in Lygia Clark's Dialogue Goggles," Documenting Fashion, 2017, https://sites.courtauld.ac.uk/documentingfashion/tag/lygia-clark/.

[128] Clark and Bois, "Nostalgia of the Body."

[129] Clark and Bois.

[130] Clark and Bois.

power of perception and being unstable in the process of fragmentation and in space.[131]



Figure 2.7 : (Left) Walter Pichler, The TV Helmet; (right) Lygia Clark, Dialogue: Google. Source: (Left) "Virtual Worlds: Walter Pichler's Futuristic Visions." Web. 22 June 2021. <**https://artselectronic.wordpress.com/2013/02/04/virtual-worlds-walter-pichlers-futurist-visions/**>. (Right) "ART AS A MEDIATOR" Web. 22 June 2021. <**https://www.guggenheim-bilbao.eus/sabias-que/el-arte-como-mediador**>.

Ugo La Pietra is a radical architect and artist noted for his complex activities that could be seen as an anti-design militancy that is difficult to analyze in theory.[132] La Pietra has become one of the important figures of radical design with original theories such as the De-balancing System that he developed in the 60s.[133] He played a role with Ettore Sottsass and Andrea Branzi in the founding of Global Tools, the first group of radical architects and designers in 1973.[134] La Pietra questions the

[131] Clark and Bois.
[132] Domus, "Ugo La Pietra," 2014, https://www.domusweb.it/en/news/2014/11/24/ugo_la_pietra.html.
[133] Radio Papesse, "Ugo La Pietra - Una Storia Milanese," Radio Papesse, 2013, http://radiopapesse.org/en/archive/interviews/ugo-la-pietra-una-storia-milanese.
[134] Papesse.

relationship between human and space with an interdisciplinary and even non-disciplinary approach.[135] Considering the environment as the phenomenology of reality, he uses himself, his body, daily life actions in a sarcastic way in his designs through audio-visual means to examine the relationship between the body and the external world for extending the design of spatial reality.[136] La Pietra's Per oggi basta! (Enough for today!) (Figure 2.8) aims to interpret the way of observing the environment by changing the perception of the physical form of the city.[137] The work, which is an 11-minute video, consists of two wooden planes joined from one edge.[138] This angle-adjustable system makes it possible to perceive the physical world in a different way.[139] The video takes the streets of Milan from this alternative perspective, reflecting an urban point of view.[140] This unconventional journey, which provides the reproduction of reality from a different perspective and leaves the experiencer with an extremely disturbing alienation, is used as an information tool that enables to understand the undecipherable aspects of the physical world and space.[141]

[135] Papesse.
[136] Domus, "Ugo La Pietra."
[137] Simona Lunatici, "The unusual point of view in 'Enough for today!' by the artist Ugo La Pietra," *CultFrame - Arti Visive* (blog), July 13, 2020, https://www.cultframe.com/2020/07/il-punto-di-vista-inusuale-in-per-oggi-basta-di-ugo-la-pietra/.
[138] Lunatici.
[139] Lunatici.
[140] Lunatici.
[141] Lunatici.



Figure 2.8 : Ugo La Pietra, Per oggi basta! (Enough for today!). Source: "Ugo La Pietra - Una storia milanese". Web. 25 June 2021. <**https://www.radiopapesse.org/en/archive/interviews/ugo-la-pietra-una-storia-milanese**>.

Gruppo T was founded in 1959 by artists Gianni Colombo, Giovanni Ancschei, Davide Boriani, and Gabriele De Vecchi, who came together in Milan.[142] What was meant by the letter "T," which represents time, was the group's aim to investigate the relationship between transformation and movement in space and time.[143] Gianni Colombo, a member of this group that reflects their phenomenological understanding of spatial perception by using different materials, has also organized many solo exhibitions.[144] In these exhibitions, Colombo designed environments that transform into alternative perceptual spaces with the interaction of body, mind, and vision.[145]

[142] Daniele Perra and Lorenza Pignatti, "Gianni Colombo," ArtReview, 2014, https://artreview.com/october-feature-gianni-colombo-1/.
[143] Perra and Pignatti.
[144] Perra and Pignatti.
[145] Perra and Pignatti.

Colombo's Spazio Elastico (1968) (Elastic Space) (Figure 2.9) is a dark cubic space perceived in different ways by the illumination of moving elastic fluorescent wires.[146] In the space, participants experience the transformation of the perception of light and dark, fullness and emptiness, presence and absence.[147] This unbalanced field that creates disorientation shows reality with alternative representations.[148]

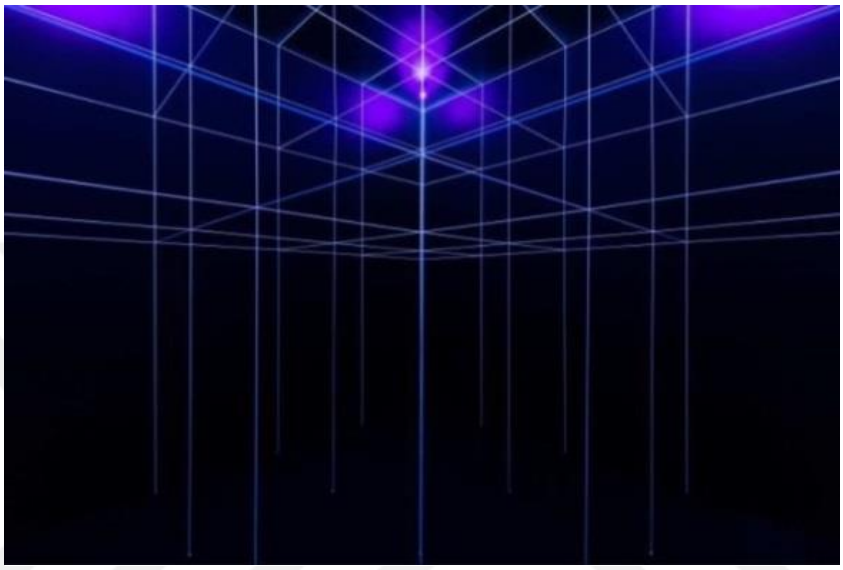


Figure 2.9 : Gianni Colombo, Spazio Elastico (Elastic Space). Source: "Gianni Colombo Spazio elastico (Elastic Space), 1967-68". Web. 25 June 2021. <**https://mobile.abc.net.au/news/2018-06-27/gianni-colombo-spazio-elastico-elastic-space-zero-at-mona/9915278?nw=0**>.

The idea of extending cognition and the brain is the common theme of these studies. Using various materials, these cognitive experiments seek to experience an alternative life and see reality in a different way by extending perception. These

[146] Perra and Pignatti.
[147] Perra and Pignatti.
[148] Perra and Pignatti.

studies investigating perception can be interpreted as searches for alternative spatial representations of reality that transform cognition.

2.6 Architectural Design for an Alternative Cognitive Domain

The works of art made on the perception of space and time also influenced the innovative architects of the period and provided the formation of a new design approach that defines architecture not with physical but with cognitive processes. Italian group Superstudio has adopted the idea of an architecture defined as a series of mental operations on reality and has produced works reflecting the concept of expanded architecture.[149] From a similar point of view, the Archizoom group criticized the approaches in which architecture was considered as a formal structure. They argued that the rationalist references of the past periods of architecture would be replaced by cognitive experiences shaped by the intellectual references of the atmosphere.[150]

> We believe in a design that can be transferred, changing only scale into different semantic areas, remaining true to itself, with no traumas or other snags. Through a series of mental operations, one can take possession of reality and thus reach serenity, the only state free from fear and anguish: in this way architecture is the means of understanding the world and knowledge of self. We are interesting mostly in conceptual and expanded architecture - architecture as criticism or philosophy,

[149] Burns, *ARTHROPODS*.
[150] Burns.

> imaginary, impossible, reflected; architecture as metaphors and parables.- Superstudio[151]

Italian architecture group Superstudio, whose dystopian visions influenced the radical design movement of the 60s, was founded in 1966 by Adolfo Natalini and Cristiano Toraldo di Francia.[152] Later, Roberto Magris, Gian Piero Frassinelli and Alessandro Poli joined the group.[153] Having an "anti-architecture" approach, the group's name "Superstudio" was actually an ironic critique of the architect's ego.[154] Interacting with design, anthropology and art, Superstudio's architecture is based on its approach to symbolically relating the reality of the physical world, which is far from being completely dissolved, to the body and life.[155] The group's non-disciplinary global projects, drawings, photocollages, films, installations, and industrial design objects spread all over the world, from Florence to Tokyo, and their approach was also discussed among other radical designers of the period.[156]

Superstudio, as an art studio with its conceptual outputs, made designs that transcend the physical space.[157] With an anti-architecture approach, they conceptualized anti-buildings and worked on neutral information and energy networks that interact with society without the necessity for the use of three-dimensional systems.[158] Considering architecture as a mental representation without any boundaries, Superstudio represents an alternative perceptual process, which explores an unalterable view of the physical world by creating a common reduction through the

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[151] Burns.
[152] Ayers, "The Sublime Dystopian Visions of Superstudio."
[153] Ayers.
[154] Ayers.
[155] Emmanuelle Chiappone-Piriou, "Superstudio Migrazioni - CIVA," e-flux Architecture, 2021, https://www.e-flux.com/announcements/368475/superstudio-migrazioni/.
[156] Chiappone-Piriou.
[157] Ventral Is Golden, "Superstudio," Visual Melt, 2021, https://visualmelt.com/Superstudio.
[158] Ventral Is Golden.

idea of an infinite grid.[159] They created utopias that explored the cosmic nature of the world with technomorphic investigations, which are metaphors for the indefinite space between the reality of the world and the metaphysical realm.[160]

With dystopias, such as II Monumento Continuo (The Continuous Monument) (Figure 2.10 (left)), Superstudio warned of the horrors of the worldwide standardization of architecture, with a grid that grew to the size of the world.[161] In Supersuperficie (Supersurface) (Figure 2.10 (right)) inspired by Information Technologies (IT) and computing, and presented at the "Italy: The New Domestic Landscape" exhibition organized by MoMA in New York in 1972, Superstudio depicted a nomadic humanity freed from labor, wandering in a constant leisure time, on a homogeneous, endless grid that contains the basic life needs of human being, such as water, light, food, and knowledge.[162] This grid, which is an endless network of energy and information, on the one hand, the minimum surface necessary for human life as a democratic proposal against class distinction, and on the other hand, it is a warning of the inevitable result of uniform architecture that has been standardized by technology.[163]

[159] "Istogrammi di architettura, 1969-2000," The Frac Centre-Val de Loire, 2021, https://www.frac-centre.fr/_en/index-authors/rub/rubprojects-317.html?authID=185&ensembleID=591&oeuvreID=9917.
[160] Ventral Is Golden, "Superstudio."
[161] Ayers, "The Sublime Dystopian Visions of Superstudio."
[162] Ayers.
[163] Ayers.



Figure 2.10 : (Left) Superstudio, II Monumento Continuo (The Continuous Monument); (right) Superstudio, Supersuperficie (Supersurface). Source: (Left) "Superstudio - Visual Melt". Web. 2 July 2021. <**https://visualmelt.com/superstudio**>. (Right) "Superstudio Migrazioni" Web. 2 July 2021. <**https://www.e-flux.com/announcements/368475/superstudio-migrazioni/**>.

In 1973 in Milan, some members of design groups such as Archizoom, 9999, Superstudio, UFO and Ziggurat, architects and designers, Ettore Sottsass, Ugo La Pietra, Davide Mosconi, Alessandro Mendini, Riccardo Dalisi, Andrea Branzi, Remo Buti, and Franco Raggi, also artists and intellectuals, Franco Vaccari, Germano Celant, Luciano Fabro and Giuseppe Chiari came together to found Global Tools, a workshop organization that lasted until 1975 (Figure 2.11 (left)).[164] This famous movement explored the possibility of configuration and alteration of cognitive processes by experimenting with the expanding cognition, spatial perception, and body through various design studies (Figure 2.11 (right)).[165] It was aimed to share the utopia of the 70s, which is a search for a cognition-based

[164] Valerio Borgonuovo and Silvia Franceschini, *Global Tools 1973-1975* (SALT/Garanti Kültür AŞ, 2015), https://saltonline.org/media/files/globaltools_scrd-1.pdf.
[165] Borgonuovo and Franceschini.

alternative design understanding, with the wider community through the critical comments made by experts and academics to the works produced in Global Tools.[166]

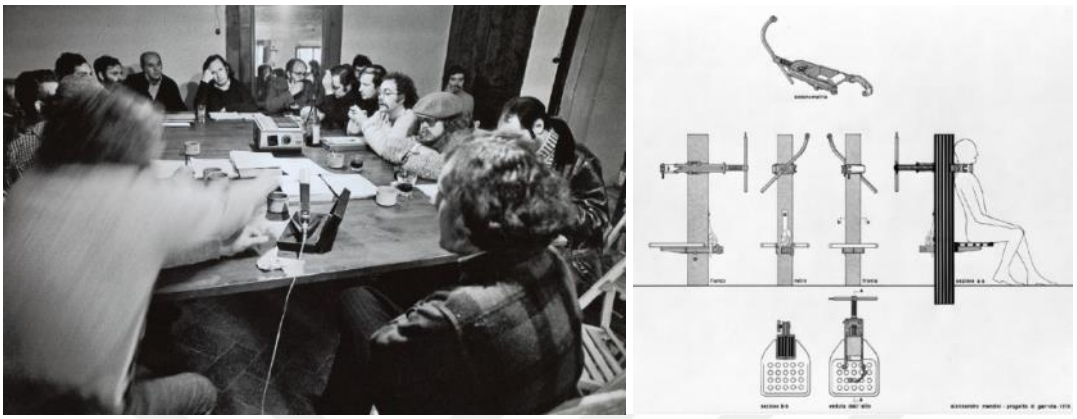


Figure 2.11 : (Left) Global Tools, Group discussions; (right) Global Tools, Progetto di Garrota (Project of a Garrote). Source: (Left) "Group discussions". Borgonuovo, V., & Franceschini, S. (Eds.). (2015). *Global Tools 1973-1975*. SALT/Garanti Kültür AŞ.(Right) "Progetto di Garrota". Borgonuovo, V., & Franceschini, S. (Eds.). (2015). *Global Tools 1973-1975*. SALT/Garanti Kültür AŞ.

Austrian architect and designer Hans Hollein designed the inflatable mobile office in 1969.[167] This installation consisted of a vacuum cleaner, PVC foil, telephone, typewriter, drawing board, pencil, thumbtacks, and rubbers.[168] The Mobile Office installation produced for television was a performance of two minutes and twenty seconds.[169] In Figure 2.12 (left), Hans Hollein works like a computer with a drawing

[166] Borgonuovo and Franceschini.
[167] Andreas Rumpfhuber, "The Architect as Entrepeneurial Self: Hans Hollein's TV Performance Mobile Office, 1969," in *The Architect as Worker : Immaterial Labor, the Creative Class, and the Politics of Design* (London ; New York: Bloomsbury Academic, 2015), https://www.ex-d.net/work/writing/the-architect-as-entrepreneurial-self.
[168] Rumpfhuber.
[169] Rumpfhuber.

board in this inflatable office within his own cognitive space.[170] In this performance, Hans Hollein, representing his private space with television, produces an architectural drawing that shows the future and architecture of a cosmopolitan, nomadic worker through cameras.[171] In this respect, Mobile Office is an architecture of information transmitted through television.[172] In this iconic design, the pneumatic balloon, which isolates the architect from the environment, is a metaphor for nomadic and precarious forms of production.[173] The Mobile Office is one of the projects that represent Hollein's approach to the abstract aspects of the built environment and media from the perspective of architecture and design.[174] Hollein designs not built architecture, but an intangible atmospheric simulation architecture, to produce an intangible environment, such as the architectural pill, the atmosphere-changing spray.[175] In his famous manifesto "Alles ist Architektur", Hollein also emphasized his approach to expand architecture and design by going beyond the three-dimensional object, which is observed in his designs.[176] "Alles Ist Architektur", which means "Everything Is Architecture" supported the theory that architecture is not a construction formalized according to a specific purpose of design but a cognitive act.[177] It explains that humans affect the environment extensively by expanding their physical and psychological domains.[178] By placing a drug-like capsule on one page of his publication (Figure 2.12 (right)), Hollein argued that architecture is actually a phenomenon that can be experimented within cognitive

[170] Rumpfhuber.
[171] Rumpfhuber.
[172] Rumpfhuber.
[173] Rumpfhuber.
[174] Rumpfhuber.
[175] Rumpfhuber.
[176] Rumpfhuber.
[177] Hollein, "Alles Ist Architektur."
[178] Hollein.

stages.[179] The radical understanding of architecture in Hollein's manifesto is also observed by Craig Buckley:

> Between these images one begins to pick up an alternate repetition present in the manifesto, one that shifts from the image of the body to its extensions. Citing the "telephone booth," the "helmets of jet pilots," and the "development of space capsules and space suits," the expansion of the human environment proceeds by becoming smaller, departing from a "building of minimal size extended into global dimensions" to approach the contours of the subject. The dynamic of extension and contraction stretches the paradoxically inclusive logic of the manifesto, which expands architecture to be identified with all things but regrounds this manifold in one thing: architecture.[180]



Figure 2.12 : (Left) Hans Hollein, The Mobile Office; (right) Hans Hollein, Architekturpille, non-physical environment. Source: (Left) "Hans Hollein, Mobile

[179] Hollein.
[180] Craig Buckley, "From Absolute to Everything: Taking Possession in 'Alles Ist Architektur,'" *Grey Room* 28 (July 2007): 108–22, https://doi.org/10.1162/grey.2007.1.28.108.

Office." Web. 10 July 2021.
<**http://www.hollein.com/eng/Architecture/Nations/Austria/Mobiles-Buero-Mobile-Office**>.
(Right) "Hans Hollein, non-physical environment (Architekturpille)". Web. 10 July 2021.
<**https://www.archdaily.com/490792/happy-birthday-hans-hollein/5331bc43c07a8056800000c2-non-physical-environ?next_project=no**>.

Coop Himmelb(l)au, who claimed, "Our architecture has no physical ground plan, but a psychic one. Walls no longer exist. Our spaces are pulsating balloons. Our heartbeat becomes space; our face is the facade," adopted a performative and spontaneous architectural approach evolving with technology:[181]

> The fascination of living in spaces-in-action that chance their pattern like clouds, to handle devices which expand the usual dimensions and reveal new psychic and physical realms. Our architecture is realized fantasies, which rely on their unexpected contrast features to set thought in motion, to influence minds through fantasy and to stimulate a new kind of sensibility and responsibility towards the environment. - Coop Himmelb(l)au[182]

Coop Himmelb(l)au has embraced an architecture that interacts with the body and the senses. Thus, the group carried out studies that expanded rationalist measures and allowed for alternative physical realms.[183] They used architecture as a means of affecting the mind through fantasy and changing the perception of the physical world.[184] Coop Himmelb(l)au's Astroballon (Figure 2.13), exhibited in Vienna in

[181] Manon Mollard, "Living in a Bubble: Smooth Surfaces to Shield," *Architectural Review* (blog), July 2, 2020, https://www.architectural-review.com/essays/living-in-a-bubble-smooth-surfaces-to-shield.
[182] Burns, *ARTHROPODS*.
[183] Burns.
[184] Burns.

1969, is a mindfulness machine that allows meditation and introspection.[185] It aims to change the regions of perceptible reality by becoming conscious of them.[186]

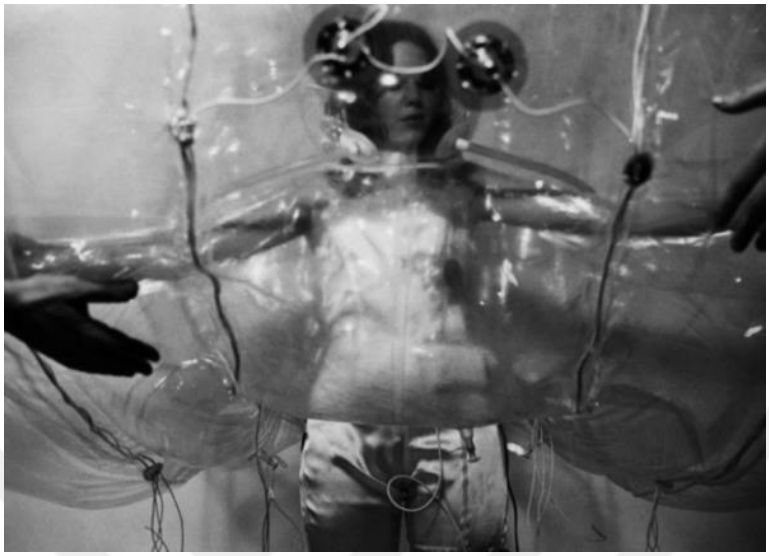


Figure 2.13 : Coop Himmelblau, Astroballon. Source: "On Astroballoons and Personal Bubbles." Web. 15 July 2021. <**https://www.e-flux.com/architecture/positions/194841/on-astroballoons-and-personal-bubbles/**>.

In Figure 2.14 (left), Wolf D Prix, Helmut Swiczinsky, and Michael Holzer, who founded Coop Himmelb(l)au in 1968, are observed walking around the city streets in a 4-meter-diameter inflatable structure called the Restless Sphere.[187] They experience the city with a completely alternative perception of space, independent of the people around, within the pneumatic structure.

Another famous project of Coop Himmelb(l)au, Villa Rosa (1968) (Figure 2.14 (right)), is an experimental space that changes form, color, smell, and sound with the

[185] Victoria Bugge Øye, "On Astroballoons and Personal Bubbles - Architecture - e-Flux," On Astroballons and Personal Bubbles, 2018, https://www.e-flux.com/architecture/positions/194841/on-astroballoons-and-personal-bubbles/.
[186] Øye.
[187] Mollard, "Living in a Bubble."

help of air used as a building element and thanks to the projectors inside.[188] In the prototype, which consists of three basic spaces, the first space has a swivel bed in the space vibrating with sound systems and projectors and ventilation that provides scents adapted to visual and auditory changes.[189] The second part is a space that changes volume through eight inflatable structures, and the last part is a mobile suitcase in the form of a shell that swells into an air-conditioned space with a bed.[190] Villa Rosa, which exemplifies that architecture is not a structural but a perceptual experience, is a living unit that contains performative experiments affecting behavioral psychology through the changes in colors, sounds, and smells. This project is an example of how architectural experience allows for a cognitive inquiry into reality and the physical world.

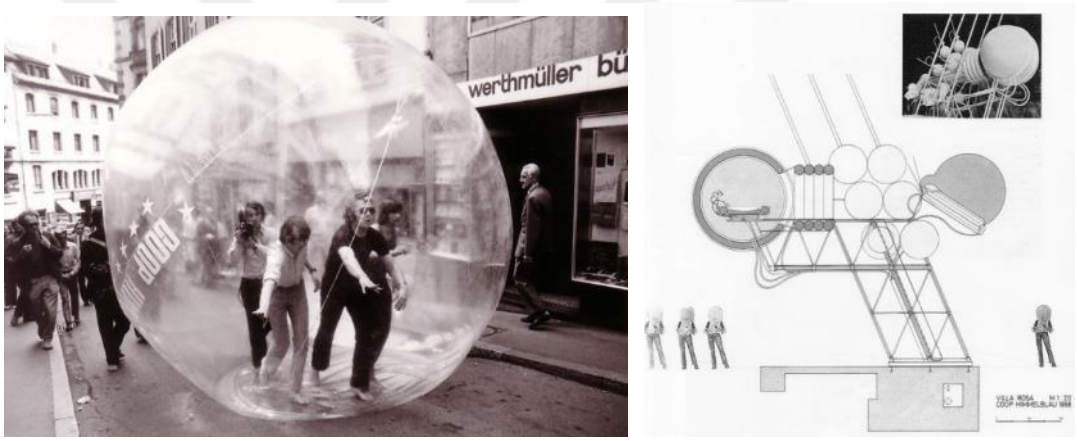


Figure 2.14 : (Left) Coop Himmelb(l)au, Restless Sphere; (right) Coop Himmelb(l)au, Villa Rosa. Source: (Left) "Living in a bubble: smooth surfaces to shield". Web. 18 July 2021. <**https://www.architectural-review.com/essays/living-in-a-bubble-smooth-**

[188] COOPHIMMELB(L)AU, "Villa Rosa - Pneumatic Living Unit: Prototype," COOPHIMMELB(L)AU, accessed December 24, 2021, https://coop-himmelblau.at/projects/villa-rosa/.
[189] COOPHIMMELB(L)AU.
[190] COOPHIMMELB(L)AU.

surfaces-to-shield?tkn=1>. (Right) "Coop Himmelblau, Villa Rosa, Pneumatic Dwelling Unit, 1968" Web. 18 July 2021. <**https://www.flickr.com/photos/23605204@N04/3394209583/**>.

Italian architect Ugo La Pietra, one of the radical designers of the 60s and 70s, initially focused on local Italian understandings, later became interested in the approaches of Walter Pichler, Hans Hollein, Raimund Abraham, Frederick Kiesler, hence the Vienna avant-garde.[191] As mentioned before, La Pietra explored the relationship between the individual and the environment, allowing the dynamics of urban space to be experienced individually. La Pietra's project, the Casa Telematica (The Domicile Cell: A Microstructure: within the Information and Communications Systems, 1971) (Figure 2.15 (left)), was presented at MOMA's exhibition "Italy: The new domestic landscape" in New York in 1972.[192] In the Casa Telematica project, the house is represented by an archetypal triangle to symbolize the collection, processing, and dissemination of information from the public to the private space.[193] Also, in the Casa Telematica, the collection, processing, and dissemination of information from the public to the private sphere are symbolized by envisioning a kind of internet system.[194] This project aims to explore the impact of the environment and atmosphere on behavioral psychology by expanding the perception of the body and physical world.

The idea of changing environmental perception using various tools and technology was explored by many designers during this period. In an interview in 2014, Günter Zamp Kelp, one of the founders of Haus-Rucker-Co, used the phrase, "We wanted to expand consciousness not by drugs but rather by new, unprecedented spaces,

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[191] Fosco Lucarelli, "Ugo La Pietra, La Casa Telematica, 1971," SOCKS, 2011, https://socks-studio.com/2011/11/22/ugo-la-pietra-la-casa-telematica/.
[192] Lucarelli.
[193] Lucarelli.
[194] Lucarelli.

objects and utilities."[195] This claim can be observed in Haus-Rucker-Co's Electric Skin outfits (1968) (Figure 2.15 (middle)), which changes the user's perception of reality through technology and various tools. Similarly, the effort to question the physical reality with technology might be observed in Archigram visionary Peter Cook modeling "Info Gonks," the Google Glass of London in 1968 (Figure 2.15 (right)), or Hans Hollein's Sunglasses Collection in 1973 (Figure 2.16).



Figure 2.15 : (Left) Ugo La Pietra, the Casa Telematica (The Domicile Cell: A Microstructure: within the Information and Communications Systems); (middle) Haus-Rucker-Co Electric Skin outfits; (right) Archigram, Info Gonks, the Google Glass of London. Source: (Left) "Ugo La Pietra, La Casa Telematica, 1971". Web. 4 August 2021. <https://socks-studio.com/2011/11/22/ugo-la-pietra-la-casa-telematica/>. (Middle) "Haus-Rucker-Co: Architectural Utopia Reloaded, Electric Skin, and Environment Transformer" Web. 4 August 2021. <**https://www.archdaily.com/582842/haus-rucker-co-architectural-utopia-reloaded/54a2c22ae58ece271f00000e-haus-rucker-co-elec?next_project=no**>. (Right) "Archigram visionary Peter Cook modelling "Info Gonks," the Google Glass of London in 1968". Web. 4 August 2021. <**http://entangled.systems/fragments/20130519-archigram-visionary-peter-cook-modelling-info-gonks-the-google-glass-of-london-in-1968.html** >.

[195] Wilk, "Space Invaders."



Figure 2.16: Hans Hollein, Sunglasses Collection. Source: "HANS HOLLEIN, SUNGLASSES COLLECTION". Web. 4 August 2021. <**http://hollein.com/eng/Design3/Sunglasses-Collection**>.

In 1970, the Haus-Rucker Co.-Live! (Figure 2.17 (left)) the exhibition opened at the Museum of Contemporary Crafts (MCC) in New York.[196] The aim of the exhibition was to present an atmosphere created by the active participation and performances of the museum visitors.[197] For this purpose, an inflatable structure with balloons on it placed on the main floor of the museum and avant-garde environments where people can observe the show from above were designed on the gallery floor.[198]

Ant Farm, a design group, working on altering perception of the environments through inflatable structures, published their design experiences and knowledge gained over time in a book called the Inflatocookbook (Figure 2.17 (right)) in 1971.[199] This book describes techniques for making various inflatable structures using the necessary material and equipment quickly and efficiently.[200] In the Inflatocookbook, many designs that are built for various events, schools, festivals, and conferences, offering alternative cognitive fields to the participants that are involved in the process are mentioned.[201]

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[196] Jessica Shaykett, "Ten Great Moments in MCC History," American Craft Council, 2015, https://www.craftcouncil.org/post/ten-great-moments-mcc-history.
[197] Shaykett.
[198] Shaykett.
[199] Ant Farm, *Inflatocookbook* (Sausalito, 1971), https://web.media.mit.edu/~bcroy/inflato-splitpages-small.pdf.
[200] Ant Farm.
[201] Ant Farm.

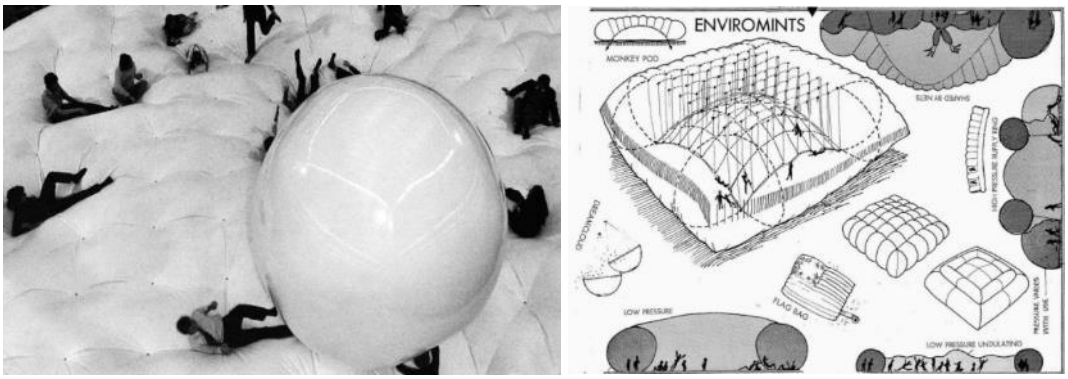


Figure 2.17 : (Left) Haus-Rucker Co.-Live!; (right) Ant Farm, Inflatocookbook. Source: (Left) "Haus-Rucker Co.'s Giant Billiard, an inflatable structure on view at the Museum of Contemporary Crafts as part of the exhibition "Haus-Rucker Co.- Live!". Web. 9 August 2021. <**https://www.craftcouncil.org/post/ten-great-moments-mcc-history**>. (Right) "Hidden Architecture, Inflatocookbook" Web. 9 August 2021. <**http://hiddenarchitecture.net/inflatocookbook/**>.

Eventstructures Research Group has produced various creative designs that offer alternative communal experiences.[202] Designing mini-environments, objects, and forms, Eventstuctures encourages people from all walks of life to be a part of spontaneous design processes by participating in group experiences together.[203] The group designs transparent tubes, air-supported PVC structures, cinema screens, projections, and experiential film devices to create pneumatic media environments.[204]

[202] Burns, *ARTHROPODS*.
[203] Burns.
[204] Burns.

Moviemovie (1967) (Figure 2.18 (left)), Eventsructures' expanded cinema performance, was designed for an experimental film festival.[205] Liquid light show effects, slides, and films were projected onto the white surfaces of the slowly inflating structure.[206] The maximum volume of the cone-shaped inflatable structure was 10 meters high and 7 meters in diameter.[207] In the space between the membranes of the structure, the performers became a part of the design by changing the shape of the inflatable tubes with their movements and playing with the balloons inside.[208] The layers of images created by the multiple surfaces on which the visual effects are reflected, and the participants, who spontaneously took off all their clothes and became a part of the cinematic show, transformed the traditional cinema screen into a three-dimensional, kinetic architectonic visualization atmosphere.[209] With the effect of the music provided by the speakers inside and outside the building, the participants who integrate with the cinematic fiction deform the shape of the pneumatic architecture, creating an immersive environment by changing the visuals.[210]

Cinematic Air Pollution Device (1967) (Figure 2.18 (right)), an extended cinema installation designed by Eventstructures, was an outdoor projection that showed projected images in smoke that was pumped between the two membranes of the 6 m x 4 m box placed at a certain height.[211] From the transparent surface of the box, the image was observed in three dimensions on the steam and smoke, as if it was moving,

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[205] Jeffrey Shaw, "MovieMovie," *Jeffrey Shaw Compendium* (blog), 2021, https://www.jeffreyshawcompendium.com/portfolio/moviemovie/.
[206] Shaw.
[207] Shaw.
[208] Shaw.
[209] Shaw.
[210] Shaw.
[211] Jeffrey Shaw, "Cinematic Air Pollution Device," *Jeffrey Shaw Compendium* (blog), 2021, https://www.jeffreyshawcompendium.com/portfolio/cinematic-air-pollution-device/.

while the patterns created by moving shadows of the smoke on the image were visible from the semi-transparent back side.[212]

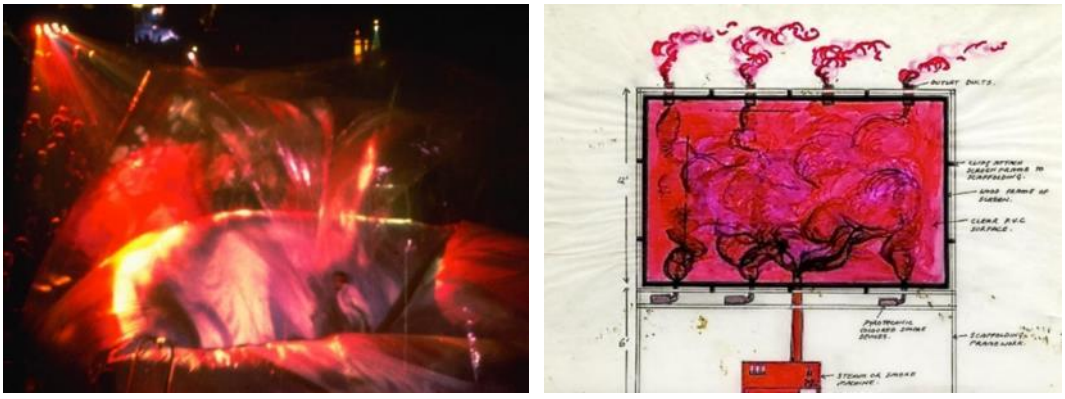


Figure 2.18 : (Left) Eventstructures Research Group, Moviemovie; (right) Eventstructures Research Group, Cinematic Air Pollution Device. Source: (Left) "MOVIEMOVIE". Web. 12 August 2021. <**https://www.jeffreyshawcompendium.com/portfolio/moviemovie/**>. (Right) "CINEMATIC AIR POLLUTION DEVICE" Web. 12 August 2021. <**https://www.jeffreyshawcompendium.com/portfolio/cinematic-air-pollution-device/**>.

The twentieth-century experiments illustrating the expansion of the human mind and vision towards the unknown have come to an end with the extinction of the counterculture in which they flourished. Interest in Extending the Mind has found a new ground in the development of cognitive and computational sciences. Nowadays, several research tracks are carried out to analyze the structure of the brain and the mysterious aspects of human perception. Recent achievements in Artificial Intelligence, fed by Neurosciences and Cognitive Sciences, contribute to the analysis of the nature of the mind. In this context, Artificial Neural Networks and Deep Learning methods shed light on human perception and visual processing. The present research, inspired by the culture of the 60s shaped by the dream of Mind Expansion,

[212] Shaw.

aims to pursue this idea of Extended Cognition in the field of computational architecture through the recent exploitation of Artificial Intelligence and Deep Learning methods.

Machine Vision is increasingly becoming a widely researched field, aiming at the further expansion of human imagination. Machine Learning methods that use collected data via various algorithms like Pattern Recognition, Neural Networks, or Artificial Generative Models in computational design are considered to bring new perspectives and opportunities to design studies. With the advancements in Artificial Neural Networks, Deep Generative Models are developed, which can outperform the previous studies. Notably, GANs (Generative Adversarial Networks), which are one of the state-of-the-art Generative Models, are highly used in all kinds of generative tasks. Other Artificial Generative Models are also used for various purposes, such as neural style transfer, deep dream, and semantic manipulation. The following chapter will examine the recent context of methodologies used in Extended Cognition research.

CHAPTER 3

COMPUTER VISION AND DEEP LEARNING FOR EXTENDED COGNITION

This chapter discusses the use of Computer Vision and Deep Learning methods for Extended Cognition approach, which is a way of studying the mind in cognitive sciences, as described in the previous chapter. The search in design cognition based on the embodiment of cognitive processes has led to the generation of alternative formal representations that will be examined and discussed in this chapter. This research aims to offer an alternative approach to the use of Computer Vision and Deep Learning methods in formal studies: To this end, this chapter first discusses some of the underlying strategies of Computer Vision to explore a methodology that enables Extended Cognition to be considered in the field of design. Then, the importance of using Artificial Neural Networks (ANNs), which is the most recent development in Computer Vision in the context of the Extended Cognition approach, is examined. Finally, Deep Generative Models, proposed with the most recent developments in ANNs, are investigated within the context of Extended Cognition research by discussing the methodologies used in current design studies.

3.1 Computational Approach to Vision for Extended Cognition

> One of the most intriguing aspects of our study of the brain is that we have learned and continue to learn about the human brain by using it to study itself. This fact leads to an interesting speculation about how far our quest can take us: Can an entity confined to itself exceed its

> boundaries and grasp all there is to know about itself? Or does the very nature of the situation limit what we can know?[213]

Classical and connectionist approaches to understanding cognitive processes are concerned with operations inside the brain in that they focus on symbolic representations or neural models of mental functioning, as explained in the previous chapter. In this respect, these approaches in cognitive science, when considered within the framework of Extended Cognition research, face the paradox that an entity expands its boundaries by staying within its own boundaries, as stated in the introductory quote to this chapter. Extended Cognition, which is an approach to understanding the mind, can allow exceeding the limits of the mind by analyzing the cognitive information coded in the outside world without being trapped in the processes inside the mind. The approaches of cognitive science provide a comprehensive framework, expressed in explicit principles, that enables systematic analysis and understanding of cognitive processes.[214] On the other hand, the Extended Cognition approach does not yet have such a systematic expression or clear principles.[215] Therefore, it may be useful to examine the computational theory of vision, which is a canonical example of cognitive science, providing an important basis in shaping subsequent research.[216] The idea of Extended Cognition would thus be discussed in a systematic context by investigating its relationship with the computational theory of vision, which is partly the founder of traditional cognitive science.[217]

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[213] Sobel and Li, *The Cognitive Sciences*.
[214] Rowlands, *The New Science of the Mind*.
[215] Rowlands.
[216] Rowlands.
[217] Rowlands.

The computational theory is a theory that explains the principles underlying the visual system.[218] This term refers to the treatment of vision as an information processing system, which is the process by which the inputs received by the eye are transformed into outputs that are various representations of the outside world.[219] In this chapter, the tasks performed at multiple levels of analysis in computational theory are explained, and the importance of computational theory in understanding vision, thereby cognitive processes, is emphasized, as related by David Marr: "Trying to understand vision by studying only neurons is like trying to understand bird flight by studying only feathers: it just cannot be done."[220] The present research thus deals with the systematic analysis and functioning of the computational theory of vision proposed by classical and connectionist approaches within the framework of Extended Cognition research. The use of Artificial Neural Networks (ANNs) is investigated as a computer vision methodology in Extended Cognition research. It is also aimed to make inferences about the ways in which cognitive information encoded in the design data of the external world can be analyzed and used for the discovery of possible extensions of design cognition through computer vision simulations.

In the 1950s and 1960s, with the application of information processing concepts to psychology, the modeling of cognitive processes through computer simulations, and the notion that the brain is an information processor, the way vision was treated fundamentally changed, and vision science began to evolve as an interdisciplinary field.[221] Simulating cognitive processes with computers made it possible to design

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[218] John P. Frisby and James V. Stone, *Seeing: The Computational Approach to Biological Vision*, 2nd ed (Cambridge: MIT Press, 2010).
[219] Frisby and Stone.
[220] Marr, *Vision*.
[221] Palmer, *Vision Science*.

artificial systems for vision science studies.[222] In the field of Artificial Intelligence (AI), a branch of computer science in which computers are programmed to simulate intelligent behavior[223], computer programs were tried to be developed to obtain information about the physical world through optical images.[224] In this way, the field is known today as computer vision has emerged. In many studies of computer vision systems that perform visual tasks, the system analyzes the information of an image used as input and then determines the locations, identities, and various properties of the contents in this input.[225] These systems may be called image processors or pattern recognizers, or if it is assumed that consciousness is related to non-biological machines, these systems may be expressed as seeing machines or perceivers.[226]

With the stimulation of the retinal cells of both eyes, the first representation of information in the visual system is formed.[227] In computational theories of vision, this retinal image is simplified as a two-dimensional and homogeneous plane of arrayed receptors.[228] The light intensity information provided by scanners and cameras is represented by numbers in the digital memory of image processing systems.[229] Without going into much detail about color and perception of gray, this system of numbers might simply be called a gray-level description.[230] The gray level or brightness of a point is more pronounced where the input image is represented with a high numerical value.[231] The representation of dark colors with low numbers

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[222] Palmer.
[223] Stuart J. Russell and Peter Norvig, *Artificial Intelligence: A Modern Approach*, 3rd ed, Prentice Hall Series in Artificial Intelligence (Englewood Cliffs, N.J: Prentice Hall, 2010).
[224] Palmer, *Vision Science*.
[225] Frisby and Stone, *Seeing*.
[226] Frisby and Stone.
[227] Palmer, *Vision Science*.
[228] Palmer.
[229] Frisby and Stone, *Seeing*.
[230] Frisby and Stone.
[231] Frisby and Stone.

and light colors with high numbers at these gray levels is compatible with the increase in the activity of a neuron in the retina as the amount of light falling on this retinal cell increases. In the representative retinal plane, square receptors called pixels, which are the representation unit of the input image, are located on the x and y axes.[232] The numerical value of each pixel represents the brightness or grayscale level of that point of the image.[233] Figure 3.1 shows the intensity values of pixels in a portion of the image. This simplified coordinate system representation of visual perception is assumed to depend on the internal structure of the retina.

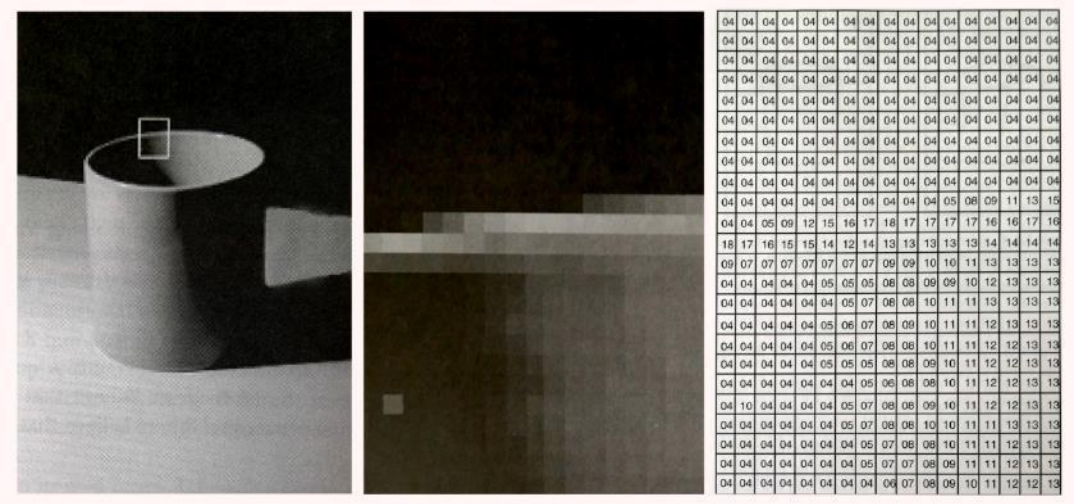


Figure 3.1: A portion of the image and its corresponding numerical array that shows the intensity of the light falling on each square pixel element. Source: "A portion of the cup scene and its corresponding numerical intensity array." Palmer, S. E. (1999). *Vision science: Photons to phenomenology*. MIT press.

In Figure 3.1, while the light intensity falling on each receptor of the gray-scale image is represented and decoded by numbers, other spatial information of the image such as edges, surfaces, and regions cannot be interpreted and explained by looking at this system. While the visual system is capable of processing and perceiving visual

[232] Palmer, *Vision Science*.
[233] Palmer.

information in detail, this numerical system designed to represent and explain visual perception does not provide information on the principles of many aspects of image processing, such as the perception of edges, the position of surfaces, and the interpretation of the object.[234] The shortcomings of this implicit scene description[235], which tries to explain the three-dimensional environment by representing it with a two-dimensional sequence of numbers, are easily noticeable in terms of understanding the visual perception processes. Also, it is a matter of discussion whether the explanation of the visual system with implicit scene descriptions is sufficient to recognize what is happening in the outside world.[236] Understanding the advanced image formation system obtained through vision requires much more information and analysis than the implicit scene descriptions; that is, all elements of the scene need to be analyzed and explicitly represented.[237] Explicit scene representations are therefore needed for the comprehension of the vision, which has improved significantly in recent years through the fields of neuroscience and machine image-processing.[238] In this respect, David Marr's approach, which explains information processing and vision through multiple levels of analysis, is essential for understanding the underlying principles of computer vision simulations to be considered in Extended Cognition research.

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[234] Palmer.
[235] Frisby and Stone, *Seeing*.
[236] Frisby and Stone.
[237] Frisby and Stone.
[238] Frisby and Stone.

3.2 Multi-Level Analysis of Information Processing and Vision

The notion of information processing aims to conceptualize and analyze the structure of the mind in a computational framework.[239] The approach to address the structure of mental processes through information processing, which is the most current framework in vision theories, makes information processing a paradigm of cognitive sciences and, therefore of interdisciplinary vision science.[240] The foundations of the computational approach to vision were laid by David Marr and his colleagues.[241] David Marr is a prominent vision scientist who provides the interdisciplinary definition of vision science with his computational vision theories and his works on the relationship of these theories to visual physiology.[242] David Marr and Tomaso Poggio describe the vision as a system of information processing.[243] This approach is called Marr's Tri-Level Hypothesis in cognitive science.[244] Marr, likening the vision to information processing in computers, defined it as follows: "Vision is a process that produces from images of the external world a description that is useful to the viewer and not cluttered with irrelevant information."[245] In vision research conducted at the Massachusetts Institute of Technology (M.I.T.) by David Marr and his colleagues, the mathematical approach to constructing working computer vision programs was most distinctly and strongly demonstrated.[246] In this research of Marr, how information about the surfaces and objects in three-dimensional space is supplied by the luminance nature of two-dimensional images is explained by

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[239] Palmer, *Vision Science*.
[240] Palmer.
[241] Frisby and Stone, *Seeing*.
[242] Palmer, *Vision Science*.
[243] D. Marr and T. Poggio, "From Understanding Computation to Understanding Neural Circuitry," May 1, 1976, https://dspace.mit.edu/handle/1721.1/5782.
[244] Dawson, *Understanding Cognitive Science*.
[245] Marr, *Vision*.
[246] Palmer, *Vision Science*.

analyses through mathematical expressions.[247] This research, which has made significant progress, has come to dominate subsequent computer vision research over the past two decades. Hence, Marr's vision research is considered as a general computational framework for the methodology of this present thesis that investigates the possible extensions of design cognition through machine vision.

David Marr (1982) suggests that complex systems based on information processing should be explained at three levels, as computational, algorithmic, and implementational, to be understood clearly.[248] Stephen Palmer notes that this theory, which is about the nature of information processing, allows analyzing the structure of vision theories, that is, the approaches to understanding vision, but not the vision itself.[249] Marr mentioned that these three levels, with crucial conceptual differences between them, are necessary to comprehend vision or other cognitive activities as an information processing.[250] The most abstract explanation in Marr's proposal, the computational level, is explained as the information constraints used to map inputs to outputs.[251] At this level, it is explained which computation should be made based on which information, without explaining how it will be done.[252]At the algorithmic level of an information processing system, there are algorithmic explanations that show how the computation is to be performed.[253] The algorithmic level, which corresponds to the concept of programming in computer science, has many ways to map the input to output, such as having different computer programs performing the same task.[254] For the task defined at the computational level, the processes that will

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[247] Marr, *Vision*.
[248] Marr.
[249] Palmer, *Vision Science*.
[250] Marr, *Vision*.
[251] Palmer, *Vision Science*.
[252] Marr, *Vision*.
[253] Marr.
[254] Palmer, *Vision Science*.

convert the representation of input to representation of output should be determined while creating the algorithmic level.[255] The implementational level, which is the last level of the information processing system, describes the embodiment of the algorithm within the physical system.[256] At the implementational level, the potential to use various devices for the physical implementation of the algorithm is similar to running a program on different computers.[257] The devices used in the physical implementation of the algorithm can be various computers as well as different brains.[258]

By adapting the mentioned information processing system to vision, Marr makes it possible to move visual perception beyond the retinal image and decompose it into stages.[259] In each of these stages, the operations that must be done to the input representations are explained in order to compute different output representations.[260] Many researchers have referred to this system of visual perception, developed by David Marr et al.,[261] by naming the stages of the system in various schemes of labeling.[262] One of these schematic methods is to name the stages of visual perception according to the types of information represented in each stage explicitly as image-based, surface-based, and object-based.[263] These stages make an important contribution to understanding vision through a systematic computational framework. At the image-based stage, image-based features are defined; that is, local lines and edges are detected and connected globally, and two-dimensional regions of the image

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[255] Marr, *Vision*.
[256] Marr.
[257] Palmer, *Vision Science*.
[258] Palmer.
[259] Marr, *Vision*.
[260] Marr.
[261] Marr.
[262] Palmer, *Vision Science*.
[263] Palmer.

are described.[264] The detection of these two-dimensional features defines the structure and organization of the images, which are then interpreted as three-dimensional scene features.[265] Marr named representations based on image-based processes as primal sketches and divided them into two:[266] According to him, in the process, he called the "raw primal sketch," basic operations such as the detection of edges and lines would take place.[267] In the other process called as "full primal sketch," local features detected in the raw primal sketch are grouped and organized globally.[268]

In the surface-based stage, which is the second level of visual processing, the visible surfaces in the outside world that form the features detected in the image-based stage are defined.[269] The information of the external world is processed by defining three-dimensional visible surfaces in this stage. Explicit surface-based representation, an intermediate level of vision, later became renown in computer vision, as it was expressed with formulas and used in computer programs.[270] Marr called his surface-based representation a "2.5-D sketch" to demonstrate that it is between the 2-D nature of image-based representation and the 3-D nature of object-based representation.[271] In the surface-based representation, visible surfaces, which supply sensory data about their inclination and distance from the observer, cannot be computed by retinal images alone.[272] Surface-based representation is achieved by giving information such as the slope, color, and distance from the observer of each

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[264] Palmer.
[265] Palmer, S. E. (1999). *Vision science: Photons to phenomenology*. MIT press.
[266] Marr, *Vision*.
[267] Marr.
[268] Marr.
[269] Palmer, *Vision Science*.
[270] Palmer.
[271] Marr, *Vision*.
[272] Palmer, *Vision Science*.

small and locally flat segment of surface in all directions towards the viewer.[273] In Figure 3.2 (left), the surface-based representation is illustrated by vectors extending radially outward from local surface segments of the object in the field of view. According to Marr's understanding of the 2.5-D sketch, in surface-based representation, there are local parts, namely surface primitives, belonging to the 2-D surfaces of the 3-D scene in the field of view.[274] These surface patches may be further customized through their properties, such as bevel, texture, and color.[275] Although the surfaces of the viewed object are locally 2-D, they are represented in 3-D in the scene.[276]

In the object-based stage, the visual system manages 3-D information about the whole scene, including the invisible parts, through assumptions about the external world.[277] An explicit representation of the entire field of view is provided, such as the inferences about invisible surfaces. In object-based processing, 3-D structures are thus recovered by hypothetically detecting the invisible parts of the objects in the space that are obscured by their visible surfaces. The volumetric approach of object-based representation considers objects as essentially three-dimensional and explicitly represents them by assembling primitive 3-D shapes.[278] According to Marr, object-based representation includes volumetric primitives that provide information about parts of the object to describe three-dimensional volumes.[279] The work of David Marr and Keith Nishihara, illustrated in Figure 3.2 (right), shows the representation of the human body as a hierarchy of volumetric parts through

[273] Palmer.
[274] Marr, *Vision*.
[275] Palmer, *Vision Science*.
[276] Marr, *Vision*.
[277] Palmer, *Vision Science*.
[278] Palmer.
[279] Marr, *Vision*.

primitive 3-D shapes.[280] Thanks to this work on the representation of 3-D shapes in computer vision, the volumetric approach has been the basis of object-oriented processing theories over the years.[281]

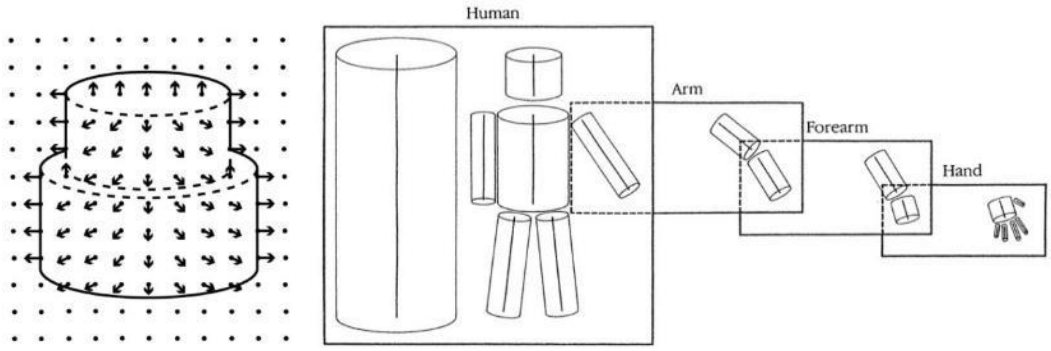


Figure 3.2 : (Left) Marr, the surface-based representation, illustration of the 2,5-D sketch; (right) Marr and Nishihara, the representation of the 3-D model as a hierarchy of volumetric parts. Source: (Left) "Illustration of the 2,5-dimensional sketch". Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. MIT press. (Right) "the organization of shape information in a 3-D model description". Marr, D. (1982). *Vision: A computational investigation into the human representation and processing of visual information*. MIT press.

Explained in a logical order as image-based, surface-based, and object-based, these phases of visual processing provide for an overarching understanding of the general nature of the computational approach to vision. In Marr's theory of vision, a visual representation of the outside world is constructed in the process of visual perception, which is initiated by stimulation of the retina, that is, by sensation.[282] In order to understand the vision, the stages of transforming the retinal stimulus, which is considered as visual input, into an output, that is, a visual representation of the external world, are

[280] D. Marr, H. K. Nishihara, and Sydney Brenner, "Representation and Recognition of the Spatial Organization of Three-Dimensional Shapes," *Proceedings of the Royal Society of London. Series B. Biological Sciences* 200, no. 1140 (February 23, 1978): 269–94, https://doi.org/10.1098/rspb.1978.0020.
[281] Palmer, *Vision Science*.
[282] Marr, *Vision*.

explicitly explained.[283] In other words, Marr explains the visual perception process as the translation of a real-world structure into a visual representation through the application of transformation principles.[284] In Marr's theory of vision, mental representations are structures that are concretized in the brains of thinking organisms.[285] The cognitive processes that occur with the transformation rules applied to mental representations are also internal because mental representations and their transformation processes take place in the brain, hence are not embodied, embedded, or extended to the outer world. [286] Thus, in Marr's theory of vision, which includes transformation rules and representations, the mind is assumed to "locate somewhere inside the head." [287] In this respect, Marr's understanding of vision differs from the Extended Cognition approach, which argues that mental processes are partially leaked out of the brain into external world objects.

On the other hand, Marr's Vision theory and Extended Cognition Hypothesis are similar in some aspects. In Marr's approach, internal structures carrying external world information undergo some transformation stages for visual perception. Similarly, in the Extended Cognition Hypothesis explained in the previous chapter, external world structures carrying cognitive information are handled as part of the cognitive process by exploiting, manipulating, and transforming.[288] Within the scope of Extended Cognition, some transformation stages related to the external world are explained and characterized as cognitive in the description of a cognitive process. Correspondingly, in Marr's vision approach, the transformation stages of internal processes are described and considered as part of cognitive processes. Therefore, it can be deduced that there is a similarity between the computational approach of vision and Extended Cognition in terms of the system used

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[283] Marr.
[284] Marr.
[285] Rowlands, *The New Science of the Mind*.
[286] Rowlands.
[287] Rowlands.
[288] Rowlands.

to explain cognitive processes. Based on this understanding, the present research investigates various transformations of design data according to the multiple stages inferring from the Tri-Level Hypothesis of information processing systems and vision for extending design cognition. These transformation stages of design data have been experienced in a project that will be related in the next chapter by considering the part-whole relationship and reference system reflecting the cognitive information of the design process for creating datasets to be used in computer vision simulations. The project will also search for the use of Artificial Neural Networks for producing possible extensions to design cognition through alternative representations. The next section will explain about Artificial Neural Networks (ANNs).

3.3 Artificial Neural Networks as a Method of Extended Cognition

The most recent development in computer vision is simulations through connective networks, namely Artificial Neural Networks (ANNs)[289] (e.g., Hinton & Anderson, 1981[290]; Feldman, 1981[291]; Grossberg, 1982[292]; Feldman & Ballard, 1982[293]).

In conventional computers, one computation at a time is fulfilled through serial processing, where the result of a computation is the input for another subsequent

[289] Palmer, *Vision Science*.
[290] Geoffrey E. Hinton and James A. Anderson, eds., *Parallel Models of Associative Memory*, Updated ed, The Cognitive Science Series (Hillsdale, N.J: L. Erlbaum, 1989).
[291] Jerome Feldman, "A Connectionist Model of Visual Memory," in *Parallel Models of Associative Memory*, Updated ed (Hillsdale, N.J: L. Erlbaum, 1989), 65–97.
[292] Stephen Grossberg, *Studies of Mind and Brain: Neural Principles of Learning,Perception, Development, Cognition, and Motor Control*, Boston Studies in the Philosophy of Science, v. 70 (Dordrecht, Holland ; Boston : Hingham, MA: D. Reidel Pub. Co. ; Sold and distributed in the U.S.A. and Canada by Kluwer Boston, 1982).
[293] J. A. Feldman and D. H. Ballard, "Connectionist Models and Their Properties," *Cognitive Science* 6, no. 3 (July 1, 1982): 205–54, https://doi.org/10.1016/S0364-0213(82)80001-3.

computation.[294] In the architecture called parallel distributed processing in ANNs, which has brain-like processing, computations are made in parallel by many computational units that do not wait for the other to finish its calculation to start working.[295] In studies of neural networks, it is assumed that the parallel functioning of the neural system in the brain directly affects vision.[296] In classical information processing models of vision, as in Marr's approach, it is avoided to give a reference to the biological structure of the brain, based on the analogy of mind-brain and program-computer functioning, and the understanding that the same mental processes can be operated equally on different hardware.[297] In other words, classical approaches claim that the functioning of the mind in the brain is similar to the working programs in computers, and the mental tasks could also be performed in other hardware like computers besides brains. Therefore, it is not needed to give any reference to the biological systems to explain about cognitive processes in classical cognitive science like Marr's theory of vision. Contrary to this understanding, connectionism is explicitly based on the nature of the brain and neural networks.[298] Patricia Churchland, Christof Koch, and Terrence Sejnowski compare brains and computers programmed to perform mental events and interestingly distinguish between the two: "…dissimilarities do not imply that brains are not computers, but only that brains are not serial digital computers."[299] The inference that can be made from this quote is that the biological brain and artificial neural networks based on the neural system are also information processing models, so they can be considered

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[294] Friedenberg and Silverman, *Cognitive Science*.
[295] Friedenberg and Silverman.
[296] Palmer, *Vision Science*.
[297] Palmer.
[298] Palmer.
[299] Patricia S Churchland, Christof Koch, and Terrence J Seinowski, "What Is Computational Neuroscience?," *Computational Neuroscience*, 1990, 12.

within the framework of the Tri-Level Hypothesis underlying the computational approach to cognition.

In information processing systems, at the computational level, the functions that the system can calculate are determined; that is, the competence of the system is defined by logic and mathematical representations.[300] In neural networks, computational descriptions are important to decide whether the network is adequate for a defined task and to generate alternative architectures to handle new cognitive tasks.[301] Connectionist researchers have produced many computational evidences to explain that neural networks are computationally capable of performing a variety of cognitive operations (e.g., Lippmann, 1987[302]; Cybenko, 1989[303]; Hartman, Keeler, & Kowalski, 1989[304]; Hornik, Stinchcombe, & White, 1989[305]; Funahashi, 1989[306]; Cotter, 1990[307]). At the computational level, by defining which input-output mappings a network can or cannot do with mathematical methods, the boundaries of the network or learning principles are determined.[308]

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[300] Dawson, *Understanding Cognitive Science*.
[301] Dawson, M. R. W. (1998). *Understanding Cognitive Science*. Oxford: Blackwell.
[302] R. Lippmann, "An Introduction to Computing with Neural Nets," *IEEE ASSP Magazine* 4, no. 2 (April 1987): 4–22, https://doi.org/10.1109/MASSP.1987.1165576.
[303] G. Cybenko, "Approximation by Superpositions of a Sigmoidal Function," *Mathematics of Control, Signals and Systems* 2, no. 4 (December 1, 1989): 303–14, https://doi.org/10.1007/BF02551274.
[304] Eric J. Hartman, James D. Keeler, and Jacek M. Kowalski, "Layered Neural Networks with Gaussian Hidden Units as Universal Approximations," *Neural Computation* 2, no. 2 (June 1, 1990): 210–15, https://doi.org/10.1162/neco.1990.2.2.210.
[305] Kurt Hornik, Maxwell Stinchcombe, and Halbert White, "Multilayer Feedforward Networks Are Universal Approximators," *Neural Networks* 2, no. 5 (January 1, 1989): 359–66, https://doi.org/10.1016/0893-6080(89)90020-8.
[306] Ken-Ichi Funahashi, "On the Approximate Realization of Continuous Mappings by Neural Networks," *Neural Networks* 2, no. 3 (January 1, 1989): 183–92, https://doi.org/10.1016/0893-6080(89)90003-8.
[307] N.E. Cotter, "The Stone-Weierstrass Theorem and Its Application to Neural Networks," *IEEE Transactions on Neural Networks* 1, no. 4 (December 1990): 290–95, https://doi.org/10.1109/72.80265.
[308] Dawson, *Understanding Cognitive Science*.

At the algorithmic level of classical approaches, the procedure for performing the specified computation is described step by step.[309] In connective networks, this procedure is the network itself; that is, neural networks provide algorithms for solving problems.[310] Therefore, the task and computational processes do not need to be fully defined in order for the connector models to start working.[311] Instead of defining the steps for the calculation, a training set is created by determining the inputs and possible outputs that will be required to perform the task.[312] Then the network is allowed to find an algorithm within the framework of the determined learning rules[313]; that is, as Daniel Hillis states, connective networks allow "for the possibility of constructing intelligence without first understanding it."[314] The information processing units, namely nodes of a three-layer network, are divided into three different levels as the input layer, hidden layer, and output layer (Figure 3.3).[315] The input layer that the stimulus reaches sends a signal to the hidden layer, and this layer feeds the output layer with the activation energy so that an output representation is formed.[316] The learning of an artificial network occurs through backpropagation.[317] In the learning process, the activation energy sent from the first activated input layer nodes to the hidden layer and then to the output layer via links provides the representation of output in the output layer.[318] Then, this initial response of the network is compared with the desired response, and the error signal of the

[309] Dawson.
[310] Dawson.
[311] Dawson.
[312] Dawson.
[313] Dawson.
[314] W. Daniel Hillis, "Intelligence as an Emergent Behavior; Or, the Songs of Eden," *Daedalus* 117, no. 1 (1988): 175–89.
[315] Friedenberg and Silverman, *Cognitive Science*.
[316] Friedenberg and Silverman.
[317] Friedenberg and Silverman.
[318] Friedenberg and Silverman.

difference between the target and the result is fed back to the output layer.[319] According to the error signal, the network modifies the weights of its links.[320] As artificial neural networks access new information, they adapt and change their response; that is, it is a simulated form of cognition that has the ability to learn.[321]

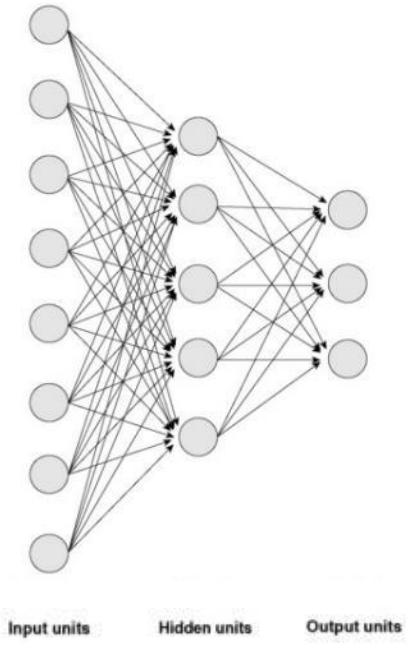


Figure 3.3: A three-layered neural network with input, hidden, and output layers.
Source: "A three-layered neural network with input, hidden, and output layers". Friedenberg, J.& Silverman, G.(2006). *Cognitive science: an introduction to the study of mind*. Sage Publications.

Many strategies of Artificial Intelligence use a problem-solving methodology called the knowledge-based approach, in which the problem and its solution are represented by symbols and conceptualized by the transformations of representations.[322] On the other hand, in the use of ANNs in Artificial Intelligence called the behavior-based

[319] Friedenberg and Silverman.
[320] Friedenberg and Silverman.
[321] Friedenberg and Silverman.
[322] Friedenberg and Silverman.

approach, problem-solving is performed by examining the general behavior of the network without focusing on the representations and rules made with symbols, leaving the computational strategy to the network.[323] However, their complex nature makes it difficult to explain how connective networks work by decoding them with analytics after training.[324] Therefore, simulating the operation of a neural network in a computer environment is essential for observing and analyzing its behavior.[325] Michael Mozer and Paul Smolensky expressed this as follows: "One thing that connectionist networks have in common with brains is that if you open them up and peer inside, all you can see is a big pile of goo." [326]Artificial neural networks themselves are types of algorithms that map inputs to outputs.[327] Therefore, neural networks trained for specific tasks allow the generation and discovery of information processing algorithms without a predefined theory.[328]

In an information processing system, the implementational level relates the nature and functioning of the system to the characteristics of its physical structure.[329] In connectionist information processing models, vision or other cognitive events are based on parallel processing in the neural system of the brain, thus developing computational architectures similar to neural processing in the brain to model mental events.[330] Thus, while connectionist networks represent a procedure for performing a task, they also represent a physical tool working for that procedure.[331] However, since Artificial Neural Networks are expected to carry only computational features

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[323] Friedenberg and Silverman.
[324] Dawson, *Understanding Cognitive Science*.
[325] Palmer, *Vision Science*.
[326] Michael C. Mozer and Paul Smolensky, "Using Relevance to Reduce Network Size Automatically," *Connection Science* 1, no. 1 (January 1, 1989): 3–16, https://doi.org/10.1080/09540098908915626.
[327] Dawson, *Understanding Cognitive Science*.
[328] Dawson.
[329] Dawson.
[330] Palmer, *Vision Science*.
[331] Dawson, *Understanding Cognitive Science*.

of biological networks, connectionist networks have been produced as oversimplified models that do not include most of the complex details of biological systems.[332] In this way, it is aimed to reach a vocabulary that allows making inferences about the functions and structural features of neural networks.[333] The design of the connectionist models based on biological neural circuits makes the connectionist approach of cognition, including vision, more effective than the classical approaches for the implementational level.[334]

As explained in the previous chapter, the desire to extend cognition continues from the past to the present. In the examples before cognitive and computer science developments, the search for cognitive extensions occurred through chemical and biological means, with the use of drugs and other stimuli. In the process of increasing formalization with the computational paradigm, the concept of Extended Cognition has begun to be examined with machine metaphors instead of the chemical and biological methods of previous design studies. Thus, research on Extended Cognition, which was phenomenological and sensual in the 20th century, became completely formalized within the computational paradigm. In this thesis, therefore, the concept of Extended Cognition is traced in two different contexts. Extended Cognition in cognitive science does not actually lead to a radical change in computational paradigm but a certain maturity in understanding the mind. In other words, the concepts of embodied, embedded, or extended cognition described in the previous chapter do not question machine metaphors in general and do not require rejection of the computational and representational methods.[335] In fact, in a broad sense, the use of functional methods of information processing of classical and connectionist approaches is the most natural way to understand the impact of the body

[332] Dawson.
[333] Dawson.
[334] Dawson.
[335] Frankish and Ramsey, *The Cambridge Handbook of Cognitive Science*.

and the external world on cognitive processes.[336] Extended Cognition studies that reveal the role of complex combined dynamics embodied action and non-biological resources in cognitive mechanisms can naturalize the functional information processing systems by adding new layers to the classical and connectionist approaches[337]

This research scrutinizes formal representations provided by the embodiment of cognitive information involved in design data. The idea of seeking for a formalization through the transformation of cognitive information coded in the external world, that is, through extensions of cognition, is based on the Extended Cognition Hypothesis. Inferring from the Tri-Level Hypothesis of information processing systems and vision, it is proposed that, while creating datasets by transforming real-world data to investigate extensions of design cognition, the data should be transformed in stages that show design stages, architectural references, and part-whole relationships.

It is considered that the use of ANNs constitute the appropriate methodology in Extended Cognition research because the connectionist network models, which is the behavior-based approach of AI, create the computational system by making inferences according to the strategies established on the inputs and outputs as in this research. In this respect, it can be argued that the complex, behavioral and brain-like nature of ANNs, which is a simulated form of cognition, will be suitable for this research and will improve the research. In addition, the idea of transforming the design data according to various stages and using it in Artificial Neural Network models will provide a naturalization by adding new layers to the functional information processing systems used in design studies. It is argued, therefore, that the generation of alternative formal representations using this method will enable the discovery of extensions to design cognition encoded in the physical world data. This argument is tested in the project that will be demonstrated in the following chapter, while the following section will discuss the use of Deep Generative

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[336] Frankish and Ramsey.
[337] Frankish and Ramsey.

Models developed with the most recent advances of ANNs, for the image-based and volumetric-based transformation of design data with examples from recent design studies.

3.4 Deep Generative Models for Extending Design Cognition

Data is a collection of information with certain characteristics. The main attributes of data are size, amount, resolution, classes, completeness, and distribution.[338] The representation is not the data itself but the initial, intermediate, or final format that configures and enables data to be used in a predefined system:[339] It can be imaged-based, volumetric, point clouds, meshes, parametric representations, skeleton representations.[340]

Generative models create new things or convert the data into different variations of representations based on data, within the same representation or in different ones.[341] In a Deep Learning system, there are feedback loops between the initial data, its representation, and the generator that learns from data.[342] 3-D Deep Learning for shapes could be used for lots of purposes like passive tasks (classification, segmentation, detection, pose estimation, matching) or active tasks (completion,

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[338] David B. Skillicorn, *Understanding Complex Datasets: Data Mining with Matrix Decompositions*, Chapman & Hall/CRC Data Mining and Knowledge Discovery Series (Boca Raton: Chapman & Hall/CRC Press, 2007).
[339] Derek Hoiem and Silvio Savarese, *Representations and Techniques for 3D Object Recognition and Scene Interpretation*, electronic resource, Synthesis Lectures on Artificial Intelligence and Machine Learning, # 15 (San Rafael, Calif. (1537 Fourth Street, San Rafael, CA 94901 USA): Morgan & Claypool, 2011), http://dx.doi.org/10.2200/S00370ED1V01Y201107AIM015.
[340] Hoiem and Savarese.
[341] Stefano Ermon and Yang Song, "Stanford University CS236: Deep Generative Models," Deep Generative Models - CS236, Fall 2021, https://deepgenerativemodels.github.io/.
[342] Ian Goodfellow, Yoshua Bengio, and Aaron Courville, *Deep Learning*, Adaptive Computation and Machine Learning Series (Cambridge, MA: MIT Press, 2016).

reconstruction, transformation, generation).[343] In passive deep learning tasks, the aim is to analyze the image, shape, or model and try to find a specific feature from that.[344] On the other hand, active deep learning tasks are not just related to observing, and they also have a synthesis part for creating some other type of data, morphing the data, reconstructing or transforming the data to create something else.[345] This thesis mainly focuses on the generation task in order to explore the possible extensions to design cognition producing alternative formal representations by using the cognitive information encoded in the design data. Generative models include the Generative Adversarial Networks (GANs),[346] Variational Autoencoders (VAEs)[347], Blend Shapes[348], and Procedural Models[349]. GANs and VAEs are categorized as in deep space while the others are in traditional space.[350]

The Deep Generative Models are used for looking at the observations and finding new samples via their distribution.[351] Recently, GANs have come to occupy an increasingly important place in computer vision:[352] GANs consist of two Artificial

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[343] Goodfellow, Bengio, and Courville.
[344] Goodfellow, Bengio, and Courville.
[345] Goodfellow, Bengio, and Courville.
[346] Ian J. Goodfellow et al., "Generative Adversarial Networks," *ArXiv:1406.2661 [Cs, Stat]*, June 10, 2014, http://arxiv.org/abs/1406.2661.
[347] Diederik P. Kingma and Max Welling, "Auto-Encoding Variational Bayes," *ArXiv:1312.6114 [Cs, Stat]*, May 1, 2014, http://arxiv.org/abs/1312.6114.
[348] Keyu Chen et al., "Modeling Caricature Expressions by 3D Blendshape and Dynamic Texture," *Proceedings of the 28th ACM International Conference on Multimedia*, October 12, 2020, 3228–36, https://doi.org/10.1145/3394171.3413643.
[349] Ilke Demir, Daniel G. Aliaga, and Bedrich Benes, "Proceduralization for Editing 3D Architectural Models," in *2016 Fourth International Conference on 3D Vision (3DV)* (2016 Fourth International Conference on 3D Vision (3DV), Stanford, CA: IEEE, 2016), 194–202, https://doi.org/10.1109/3DV.2016.28.
[350] Ruoqi Wei et al., "Variations in Variational Autoencoders - A Comparative Evaluation," *IEEE Access* 8 (2020): 153651–70, https://doi.org/10.1109/ACCESS.2020.3018151.
[351] Goodfellow, Bengio, and Courville, *Deep Learning*.
[352] Zhengwei Wang, Qi She, and Tomas E. Ward, "Generative Adversarial Networks in Computer Vision: A Survey and Taxonomy," *ArXiv:1906.01529 [Cs]*, December 29, 2020, http://arxiv.org/abs/1906.01529.

Neural Networks, the one is 'Generator G' for generating new samples, and the other is 'Discriminator D' for evaluating the generated samples (Figure 3.4).[353] These models play a two-player game to better themselves at each turn: At each iteration, the Discriminator gets better at identifying fake samples, and the Generator, using the feedback from the Discriminator, generates more realistic samples to fool the Discriminator.[354] GANs are one of the state-of-the-art Generative Models and are highly used in all kinds of generative tasks.[355] Alternative representations of design data in various concepts can be received and interpreted through GAN models, which are trained with various datasets. In the project demonstrated in the next chapter testing the hypothesis of the research, a GAN is used to generate new samples from the learned cognitive information encoded in an architectural structure.

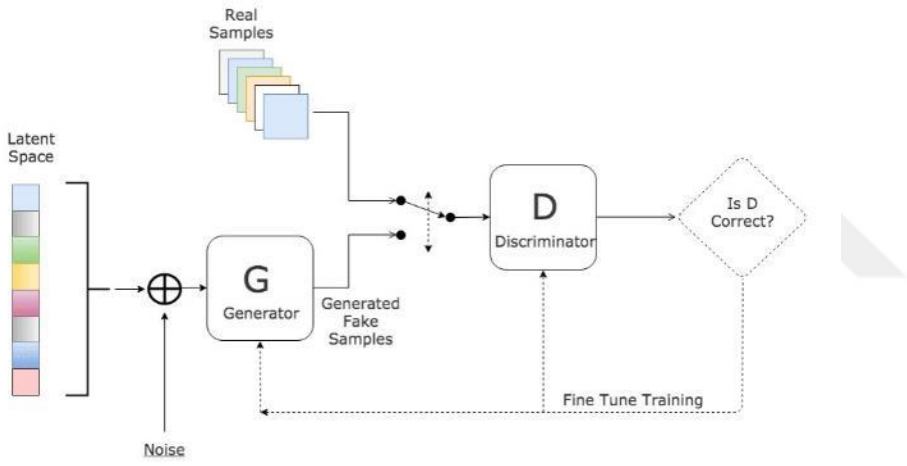


Figure 3.4 : Generative Adversarial Network (GAN). Source: "Generative Adversarial Network". Web. 10 September 2021. <https://www.kdnuggets.com/2017/01/generative-adversarial-networks-hot-topic-machine-learning.html>.

[353] Goodfellow et al., "Generative Adversarial Networks."
[354] Goodfellow et al.
[355] Wang, She, and Ward, "Generative Adversarial Networks in Computer Vision."

The common GAN applications are recently used to transform and manipulate the alternative representations of design data. There are types of GANs such as Conditional GAN (CGAN)[356] that aim to control some characteristics of the generated data by adding a condition parameter and by adding extra input data to both the Generator and the Discriminator. 3D-GAN[357] generates 3D objects from a probabilistic space by leveraging recent advances in volumetric convolutional networks and generative adversarial nets. SinGAN[358] uses a multi-layer GAN structure. Each layer has a separate GAN model, and the output of each GAN is given to the next GAN.[359] Point Cloud GAN (PC-GAN)[360] proposes a two-fold modification to GAN algorithm for learning to generate point clouds. StyleGAN[361] aims to produce realistic images. Progressive growing of GAN (PG-GAN)[362] gradually enlarges a GAN and produces higher resolution images at each tier. Wasserstein GAN (wGAN)[363] obtains a more balanced GAN training by changing the loss function of GAN.

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[356] Mehdi Mirza and Simon Osindero, "Conditional Generative Adversarial Nets," *ArXiv:1411.1784 [Cs, Stat]*, November 6, 2014, http://arxiv.org/abs/1411.1784.
[357] Jiajun Wu et al., "Learning a Probabilistic Latent Space of Object Shapes via 3D Generative-Adversarial Modeling," *ArXiv:1610.07584 [Cs]*, January 4, 2017, http://arxiv.org/abs/1610.07584.
[358] Tamar Rott Shaham, Tali Dekel, and Tomer Michaeli, "SinGAN: Learning a Generative Model from a Single Natural Image," *ArXiv:1905.01164 [Cs]*, September 4, 2019, http://arxiv.org/abs/1905.01164.
[359] Shaham, Dekel, and Michaeli.
[360] Chun-Liang Li et al., "Point Cloud GAN," *ArXiv:1810.05795 [Cs, Stat]*, October 13, 2018, http://arxiv.org/abs/1810.05795.
[361] Tero Karras, Samuli Laine, and Timo Aila, "A Style-Based Generator Architecture for Generative Adversarial Networks," *ArXiv:1812.04948 [Cs, Stat]*, March 29, 2019, http://arxiv.org/abs/1812.04948.
[362] Tero Karras et al., "Progressive Growing of GANs for Improved Quality, Stability, and Variation," *ArXiv:1710.10196 [Cs, Stat]*, February 26, 2018, http://arxiv.org/abs/1710.10196.
[363] Martin Arjovsky, Soumith Chintala, and Léon Bottou, "Wasserstein Generative Adversarial Networks," in *Proceedings of the 34th International Conference on Machine Learning* (International Conference on Machine Learning, PMLR, 2017), 214–23, https://proceedings.mlr.press/v70/arjovsky17a.html.

Another Generative Model categorized as in deep space is AutoEncoders, encoder-decoder models which are used in the studies of Artificial Neural Networks. They are used for encoding the data into reduced dimensions and then decoding it to get the input data again.[364] The aim is to represent the data in lower dimensions, extracting important features and learning underlying structures in the data with minimum error. An AutoEncoder has been used in the project explained in the next chapter to learn and encode the common features of input samples.

3.5 Image-based 3-D Deep Learning to Transform the Design Data

In generative 3-D Deep Learning models, the fundamental representation of data consists of image-based, volumetric (pixels or voxels), point cloud, mesh, and graph-based.[365] Image-based 3-D Deep Learning models use 2-D shapes for providing 3-D objects. In one of the first 3-D Deep Learning papers, Multi-view Convolutional Neural Networks (CNNs) use images of 3-D models from various angles and combine them with the trained model to obtain new 3-D configurations (Figure 3.5).[366]

[364] Kingma and Welling, "Auto-Encoding Variational Bayes."
[365] Siddhartha Chaudhuri et al., "Learning Generative Models of 3D Structures," *Computer Graphics Forum* 39, no. 2 (2020): 643–66, https://doi.org/10.1111/cgf.14020.
[366] Maxim Tatarchenko, Alexey Dosovitskiy, and Thomas Brox, "Multi-View 3D Models from Single Images with a Convolutional Network," *ArXiv:1511.06702 [Cs]*, August 2, 2016, http://arxiv.org/abs/1511.06702.

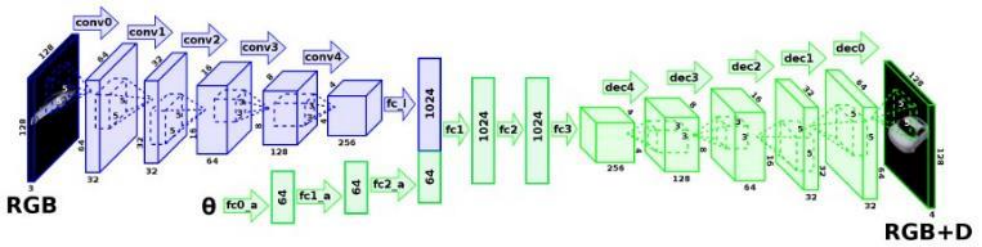


Figure 3.5 : The architecture of Multi-view Convolutional Neural Network. The encoder (blue) turns an input image into an abstract 3-D representation. The decoder (green) renders the final image. Source: "The architecture of Convolutional Network for Multi-view 3D Models". Tatarchenko, M., Dosovitskiy, A., & Brox, T. (2016). Multi-view 3D models from single images with a convolutional network. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *9911 LNCS*, 322–337. https://doi.org/10.1007/978-3-319-46478-7_20

There are also other methods for view synthesis that create views of a 3-D model by using a view from a different angle.[367] One of the limitations of image-based 3-D Deep Learning is that it cannot capture the global shape because of looking from definite views, and it is limited by 2-D CNNs. Therefore, there are always view sampling problems, although it is easy to obtain or create 2-D data.

To improve the use of image-based Deep Learning methods on artworks, Leon A. Gatys, Alexander S. Ecker, and Matthias Bethge designed a Neural Algorithm of Artistic Style, which could create connections with content and style image, then recombine them.[368] This algorithm provides an opportunity to produce new images that have the content of various photographs with the appearance of several artworks (Figure 3.6). Image-based Deep Learning has been widely applied in design studies with the development of the neural style transfer method used for the production of alternative representations on artworks.

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[367] Tinghui Zhou et al., "View Synthesis by Appearance Flow," *ArXiv:1605.03557 [Cs]*, February 11, 2017, http://arxiv.org/abs/1605.03557.
[368] Leon A. Gatys, Alexander S. Ecker, and Matthias Bethge, "A Neural Algorithm of Artistic Style," *ArXiv:1508.06576 [Cs, q-Bio]*, September 2, 2015, http://arxiv.org/abs/1508.06576.



Figure 3.6: Image representation that combine the content of a photograph with the style of artwork in a Convolutional Neural Network (CNN). Source: "Image representations in a Convolutional Neural Network (CNN)". Gatys, L. A., Ecker, A. S., & Bethge, M. (2015). A neural algorithm of artistic style. *arXiv preprint arXiv:1508.06576*.

The style transfer based on Deep Neural Network could create alternative representations via a proper dataset, so Neural Style Transfer (NTS) was started to be used as a design method using architectural images. Yue Ren and Hao Zheng (2020) tested the neural style transfer technique on the content of architectural visuals with different style images. They observed the change in output by manipulating the weight of content and style images with an architectural sample (Figure 3.7).[369] Silvestere et al. also searched for a neural style algorithm with an architectural style and architectural content to observe the effect of architectural style on another context via Convolutional Neural Network (Figure 3.8).[370] In this study, the style transfer technique was used directly to transform the architectural content with a different architectural style instead of applying it to an architectural content and a style related to nature or art. And as a result, an alternative output was obtained

[369] Yue Ren and Hao Zheng, "The Spire of AI - Voxel-Based 3D Neural Style Transfer," in *D. Holzer, W. Nakapan, A. Globa, I. Koh (Eds.), RE: Anthropocene, Design in the Age of Humans - Proceedings of the 25th CAADRIA Conference - Volume 2, Chulalongkorn University, Bangkok, Thailand, 5-6 August 2020, Pp. 619-628* (CUMINCAD, 2020), http://papers.cumincad.org/cgi-bin/works/paper/caadria2020_091.

[370] Joaquim Silvestre, Yasushi Ikeda, and Francois Guena, "Artificial Imagination of Architecture with Deep Convolutional Neural Network," in *Living Systems and Micro-Utopias: Towards Continuous Designing, Proceedings of the 21st International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2016*, 2016, 881–90.

to expand the formal representation of the architectural content using another design data.



Figure 3.7 : The effect of style on generated output. Source: "The Effect of Style Weight (0-1000000) On the Generated Outputs.". Ren, Y. U. E., & Zheng, H. A. O. (2020). *The spire of ai*. *2*, 619–628.



Figure 3.8 : Architect style on architecture content. Source: "If the pictures are wisely chosen, it's possible to use this algorithm with architect style on content". Silvestere, J., Ikeda, Y., & Guena, F. (2016). Artificial Imagination of Architecture with Deep Convolutional Neural Network. *Living Systems and Micro-Utopias: Towards Continuous Designing, Proceedings of the 21st International Conference of the Association for Computer-Aided Architectural Design Research in Asia CAADRIA 2016*, 881–890.

In the study called Church of AI, Deep Learning algorithms were used with the neural style transfer approach. (Figure 3.9) Two 2-D databases were created for this work. One of them was modernist, and the other was Baroque.[371] In this work, the design data of two different architectural styles are transformed, and an alternative representation of this data is produced that extends visual representations.

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[371] Matias del Campo, "The Church of AI - An Examination of Architecture in a Posthuman Design Ecology," in *M. Haeusler, M. A. Schnabel, T. Fukuda (Eds.), Intelligent & Informed - Proceedings of the 24th CAADRIA Conference - Volume 2, Victoria University of Wellington, Wellington, New Zealand, 15-18 April 2019, Pp. 767-772* (CUMINCAD, 2019), http://papers.cumincad.org/cgi-bin/works/paper/caadria2019_553.

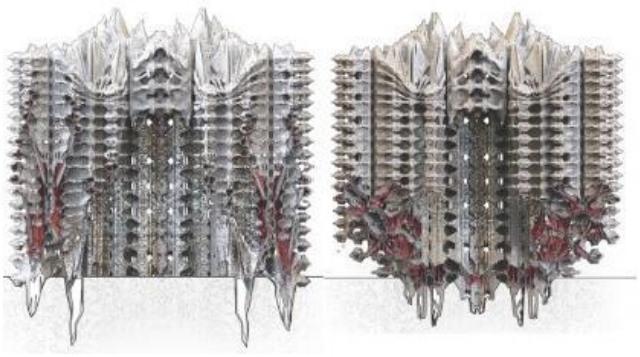
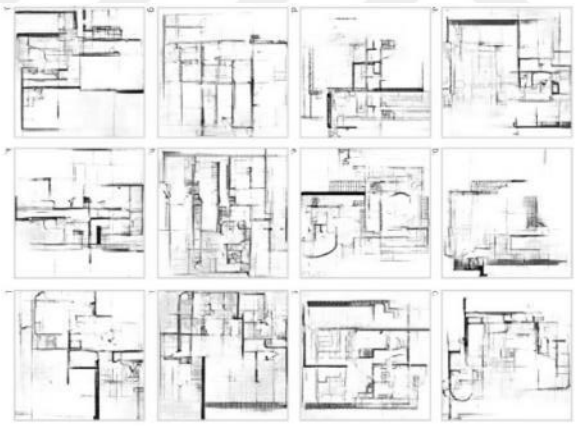


Figure 3.9: The Church of AI. Source: "Section through one of the resulting models. (Image: Marianna Sanche & Leetee Wang, PennDesign, University of Pennsylvania 2018)". Campo, M. D. E. L., Manninger, S., Sanche, M., & Wang, L. (2019). *The church of ai*. *2*, 767–772.

In another study by David Newton on Deep Generative Models using a dataset that included house plans which have a specific architectural character, a GAN was used to generate new plans that had the features of this architecture (Figure 3.10).[372] This was an example of learning the underlying style of design data to produce further representations having the principles of input data.



[372] David Newton, "Deep Generative Learning for the Generation and Analysis of Architectural Plans with Small Datasets," in *Sousa, JP, Xavier, JP and Castro Henriques, G (Eds.), Architecture in the Age of the 4th Industrial Revolution - Proceedings of the 37th ECAADe and 23rd SIGraDi Conference - Volume 2, University of Porto, Porto, Portugal, 11-13 September 2019, Pp. 21-28* (CUMINCAD, 2019), http://papers.cumincad.org/cgi-bin/works/paper/ecaadesigradi2019_135.

Figure 3.10: Samples of GAN generated plans. Source: Newton, D. (2020). *Deep Generative Learning for the Generation and Analysis of Architectural Plans with Small Datasets*. *2*, 21–28. https://doi.org/10.5151/proceedings-ecaadesigradi2019_135

In the study called Imaginary Plans (Figure 3.11), with a collected dataset consisting of various plans and topographical maps, a GAN was trained to learn the physical features of the images. Progressive Growing GAN was used for training, complemented by Style Transfer techniques.[373]

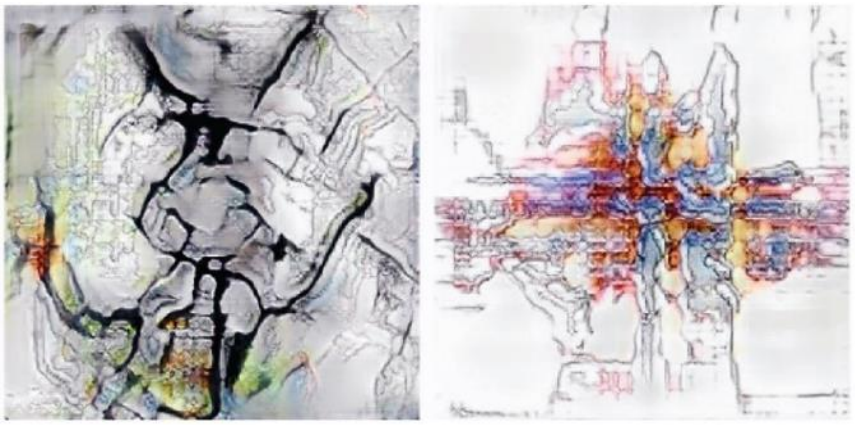


Figure 3.11 : Results of 2-D to 2-D Style transfers based on plans. Source: Campo, M. Del, Manninger, S., & Carlson, A. (2019). Imaginary Plans the potential of 2D to 2D Style transfer in planning processes. Ubiquity and Autonomy - Paper Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2019, 412–418.

Matias Del Campo, Sandra Manninger, and Alexandra Carlson in their paper called Hallucinating Cities relate the use of neural networks on urban features, exemplified

[373] Matias Del Campo, Sandra Manninger, and Alexandra Carlson, "Imaginary Plans: The Potential of 2D to 2D Style Transfer in Planning Processes," in *ACADIA 19:UBIQUITY AND AUTONOMY [Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA) ISBN 978-0-578-59179-7] (The University of Texas at Austin School of Architecture, Austin, Texas 21-26 October, 2019) Pp. 412-418* (CUMINCAD, 2019), http://papers.cumincad.org/cgi-bin/works/paper/acadia19_412.

with case studies (Figure 3.12). 2-D to 2-D style transfer methods were used to differentiate urban features and design new proposals.[374]

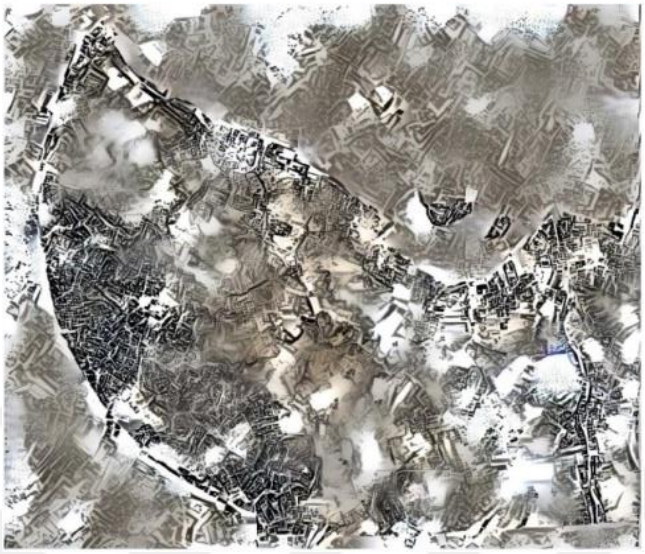


Figure 3.12 : Result of Style transfer between a Dataset of Nolli maps of known cities.
Source: Campo, M. D., Manninger, S., & Carlson, A. (2020, May). Hallucinating cities: a posthuman design method based on neural networks. In *Proceedings of the 11th Annual Symposium on Simulation for Architecture and Urban Design* (pp. 1-8).

After the 2-D to 2-D studies in the field, the developments on image-based 3-D Deep Learning were carried over to the design field, and alternative 3-D representations were started to be produced using 2-D drawings or visuals. Thus, computer vision studies began to be utilized in the multidimensional environment, which has more potential in terms of extending visual perception and producing alternative representations in the field of design. Kato et al. developed a method to relate rendering with neural networks: They performed 3-D models with images, considered as the first 3-D Deep Dream with a 2-D source in computer science

[374] Matias Del Campo, Sandra Manninger, and Alexandra Carlson, "Hallucinating Cities: A Posthuman Design Method Based on Neural Networks," in *Proceedings of the 11th Annual Symposium on Simulation for Architecture and Urban Design*, SimAUD '20 (San Diego, CA, USA: Society for Computer Simulation International, 2020), 1–8.

(Figure 3.13).[375] This 3-D neural rendering study in computer science has had a significant impact on the use of 2-D data for alternative 3-D representations in design studies.

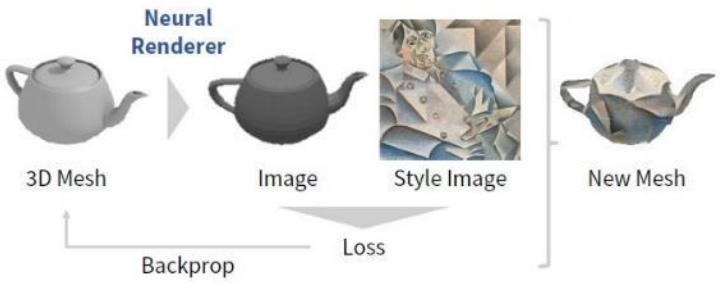


Figure 3.13: 2-D to 3-D style transfer. Source: Kato, H., Ushiku, Y., & Harada, T. (2018). Neural 3d mesh renderer. In *Proceedings of the IEEE conference on computer vision and pattern recognition* (pp. 3907-3916).

The neural style transfer techniques were then expanded to the 3-D environment, such as in the project of Robot Garden (Figure 3.14) that used neural networks for the ground features of a robot garden. In the study, 2-D texture editing techniques were applied to render in a 3-D environment.[376]

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[375] Hiroharu Kato, Yoshitaka Ushiku, and Tatsuya Harada, "Neural 3D Mesh Renderer," *ArXiv:1711.07566 [Cs]*, November 20, 2017, http://arxiv.org/abs/1711.07566.
[376] Matias del Campo, Alexandra Carlson, and Sandra Manninger, "Towards Hallucinating Machines - Designing with Computational Vision," *International Journal of Architectural Computing* 19, no. 1 (March 1, 2021): 88–103, https://doi.org/10.1177/1478077120963366.



Figure 3.14 : A side view of the Robot Garden. Source: Del Campo, M., Carlson, A., & Manninger, S. (2021). Towards Hallucinating Machines-Designing with Computational Vision. *International Journal of Architectural Computing*, *19*(1), 88-103.

Hang Zhang and Ezio Blasetti used 3-D models for training GAN.[377] The study transforms 3-D models into 2-D images for use in the system. Various popular Generative Models, such as Pix2Pix[378] and CycleGAN[379], were used in this research consisting of an alternative application of Neural Style Transfer, where the aim was to create a 3-D form by positioning 2-D outputs in different directions (Figure 3.15).[380]

[377] Hang Zhang and Ezio Blasetti, "3D Architectural Form Style Transfer through Machine Learning," in *D. Holzer, W. Nakapan, A. Globa, I. Koh (Eds.), RE: Anthropocene, Design in the Age of Humans - Proceedings of the 25th CAADRIA Conference - Volume 2, Chulalongkorn University, Bangkok, Thailand, 5-6 August 2020, Pp. 659-668* (CAADRIA, CUMINCAD, 2020), http://papers.cumincad.org/cgi-bin/works/paper/caadria2020_234.
[378] Phillip Isola et al., "Image-to-Image Translation with Conditional Adversarial Networks," *ArXiv:1611.07004 [Cs]*, November 26, 2018, http://arxiv.org/abs/1611.07004.
[379] Jun-Yan Zhu et al., "Unpaired Image-to-Image Translation Using Cycle-Consistent Adversarial Networks," *ArXiv:1703.10593 [Cs]*, August 24, 2020, http://arxiv.org/abs/1703.10593.
[380] Zhang and Blasetti, "3D Architectural Form Style Transfer through Machine Learning."

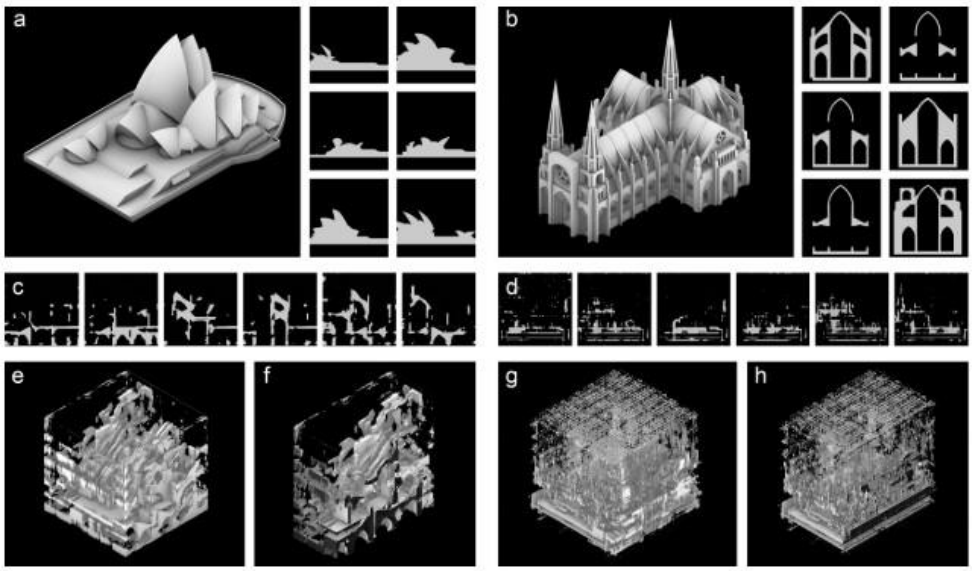


Figure 3.15 : The method and results of multiple axes through CycleGAN. Source: Zhang, H. (2019). 3D Architectural Form Style Transfer through Machine Learning. *Porceedings of the 25th International Conference of the Association for Computer-Aided Architectural Design Research*, *December*.

In another study, Hang Zhang aimed to generate 3-D models with StyleGAN[381] , which is a state-of-the-art Generative Model that was trained with the reconstruction of 3-D models in various complex concepts.[382] It was mentioned that the 3-D model is composed of changing images, and these images were used as a dataset to create new 3-D models on various complexity levels of input (Figure 3.16).

[381] Karras, Laine, and Aila, "A Style-Based Generator Architecture for Generative Adversarial Networks."
[382] Hang Zhang, "3D Model Generation on Architectural Plan and Section Training through Machine Learning," *Technologies* 7, no. 4 (December 2019): 82, https://doi.org/10.3390/technologies7040082.

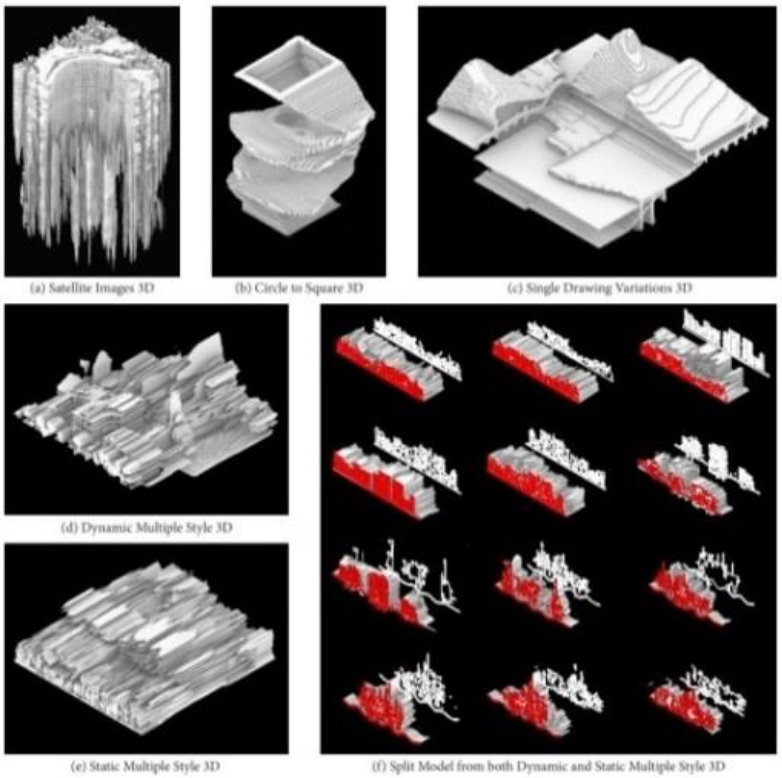


Figure 3.16 : 3-D models generated from truncation trick images of training results.
Source: Zhang, H. (2019). 3D Model Generation on Architectural Plan and Section Training through Machine Learning. Technologies, 7(4), 82. https://doi.org/10.3390/technologies7040082

Kelsey Song, Sichang Xu, and Xinlu Sun worked on Progressively Grown GAN in their thesis project.[383] Observing some inconsistencies with the artworks contained in the Louvre museum, they redesigned the exhibition space by referencing the artworks inside.[384] (Figure 3.17 (left)) Isolating the backgrounds of the artworks, they created a dataset with the backgrounds of images (Figure 3.17 (right)).[385] They detected the connected vertical and horizontal lines in the background of images

[383] Kelsey Song, Sichang Xu, and Xinlu Sun, "The Architecture of Sfumato" (The Architecture of Sfumato, Taubman College, 2020), https://taubmancollegethesis.com/TEXT_Kelsey-Song-Sichang-Xu-Xinlu-Sun.
[384] Song, Xu, and Sun.
[385] Song, Xu, and Sun.

using Progressively Grown GAN (Figure 3.18 (left)).[386] The images created by PGGAN were used to create a 3D model ((Figure 3.18 (right)) by placing them in different views and adapting them to the 3D environment (Figure 3.19).[387]

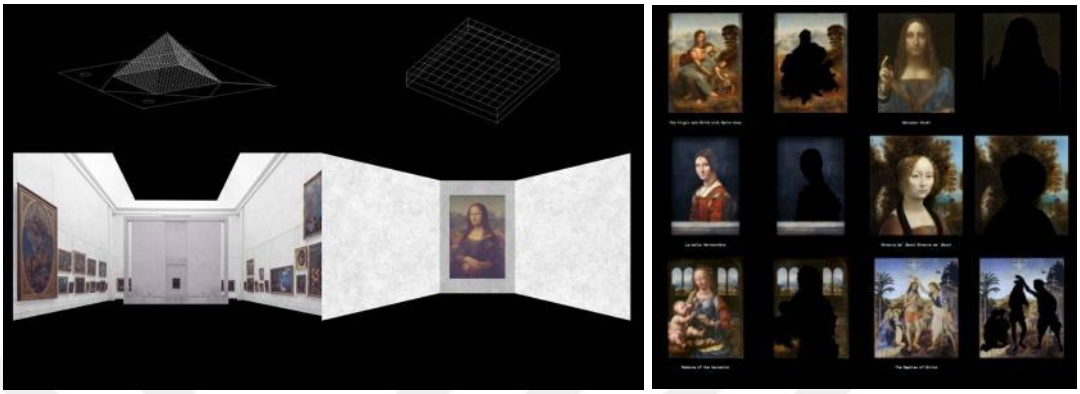


Figure 3.17 : (Left) The proposal for designing a new exhibition space for artworks; (right) Backgrounds of artworks for the dataset. Source: (Left) "The Architecture of Sfumato". Web. 10 October 2020. <https://arch-ai.org/>. (Right) "The Architecture of Sfumato" Web. 10 October 2020. <https://arch-ai.org/>.

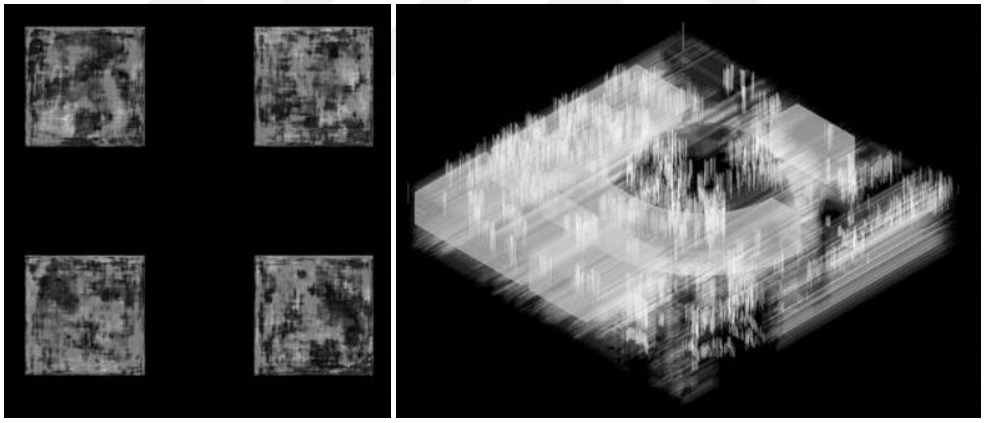


Figure 3.18 : (Left) Part of PGGAN Results; (right) a 3D project designed by PGGAN. Source: (Left) "The Architecture of Sfumato". Web. 10 October 2020. <https://arch-ai.org/>. (Right) "The Architecture of Sfumato" Web. 10 October 2020. <https://arch-ai.org/>.

[386] Song, Xu, and Sun.
[387] Song, Xu, and Sun.

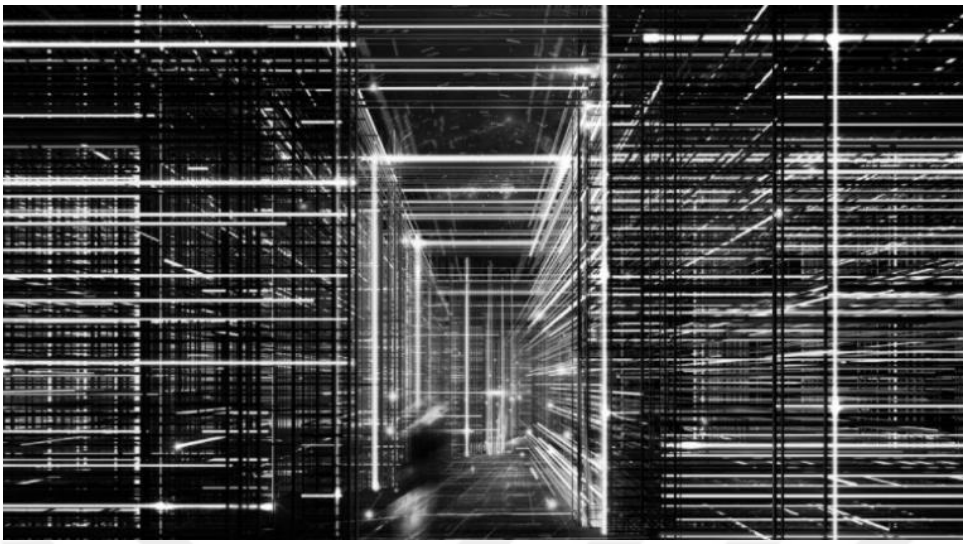


Figure 3.19: Render from the environment. Source: "The Architecture of Sfumato". Web. 10 October 2020. <https://taubmancollegethesis.com/TEXT_Kelsey-Song-Sichang-Xu-Xinlu-Sun>.

Roberto Corpus, Tianci Liang, and Ruxin Xie worked on a new form-finding method in their thesis project.[388] They designed a dataset with images obtained from nature that could inspire alternative architectural forms. They applied neural style transfer algorithms to the sections of conventional models and natural images (Figure 3.20). Their aim was to obtain the transformation of conventional architectural solutions. After taking the results of style transfer processes, they entered into post-processing with Z-Brush and 3-D modeling environments to transfer the images to a 3-D model (Figure 3.21).[389]

[388] Roberto Corpus, Tianci Liang, and Ruxin Xie, "Collaborative Agency of Architecture AI" (Taubman College, 2020), https://taubmancollegethesis.com/TEXT_Roberto-Corpus-Tianci-Liang-Ruxin-Xie.
[389] Corpus, Liang, and Xie.

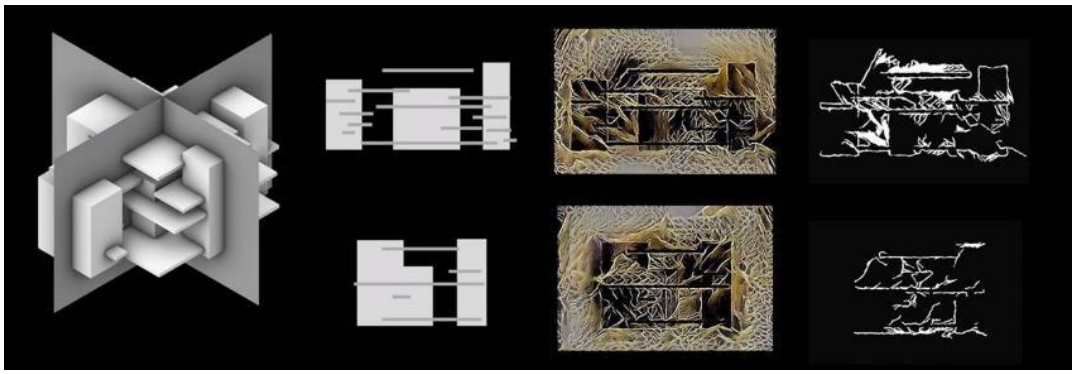


Figure 3.20 : Style Transfer between natural style and conventional content. Source: "Collaborative Agency of Architecture AI". Web. 12 October 2020. <https://arch-ai.org/>.

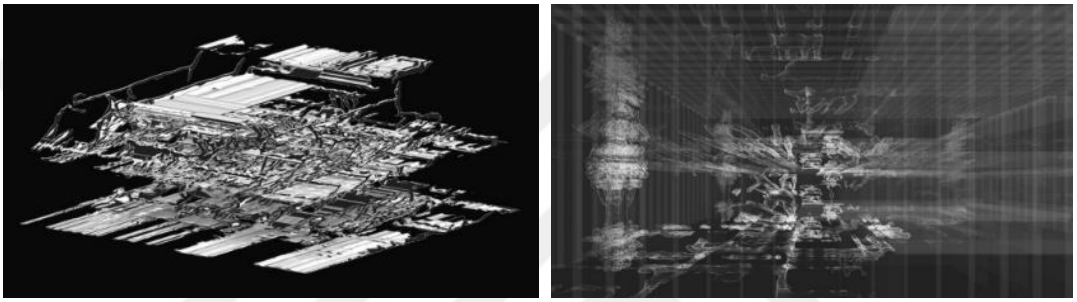


Figure 3.21 : The results of post-processing. Source: (Left) "Collaborative Agency of Architecture AI". Web. 12 October 2020. <https://arch-ai.org/>. (Right) "Collaborative Agency of Architecture AI" Web. 20 October 2021. <https://taubmancollegethesis.com/TEXT_Roberto-Corpus-Tianci-Liang-Ruxin-Xie>.

Marry Greenert, Fa Zhe Ren, and Anh Thu Vuong searched for the correlation between nature and architecture in their thesis project.[390] They produced two datasets, one from patterns in nature and the other from architectural spaces. Dataset of over 4,000 images was used for style transfer and for the unpaired image to image translation with CycleGAN (Figure 3.22). They then applied the outputs of

[390] Marry Greenert, Fa Zhe Ren, and Anh Thu Vuong, "Sensorial Space in the Age of A.I." (Sensorial Space in the Age of A.I., Taubman College, 2020), https://taubmancollegethesis.com/TEXT_Mary-Greenert-Fa-Zhe-Ren-Anh-Thu-Vuong.

CycleGAN on a decided context to observe how these images with natural and artificial patterns could shape a 3-D architectural environment (Figure 3.23).[391]

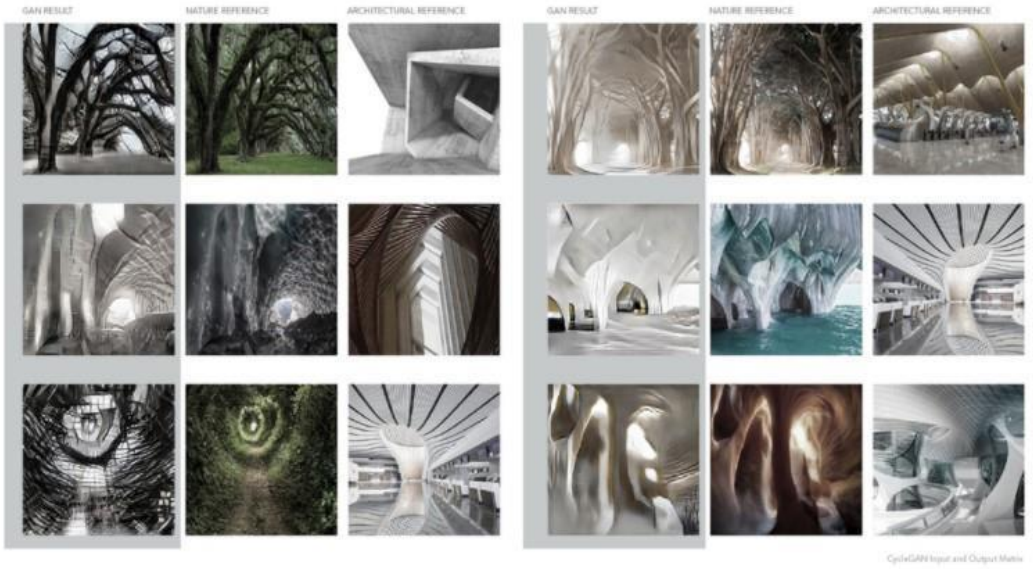


Figure 3.22 : Dataset with natural and artificial images and Style Transfer results on images. Source: "Sensorial Space in the Age of A.I.". Web. 25 November 2021. <https://taubmancollegethesis.com/TEXT_Mary-Greenert-Fa-Zhe-Ren-Anh-Thu-Vuong >.

[391] Greenert, Ren, and Vuong.



Figure 3.23: 3-D environment reshaped by nature-inspired architectural features.
Source: "Sensorial Space in the Age of A.I.." Web. 25 November 2021. <https://taubmancollegethesis.com/TEXT_Mary-Greenert-Fa-Zhe-Ren-Anh-Thu-Vuong >.

Henan Liu, Longtai Liao, and Akshay Srivastava produced 3-D model parts that have a reference to specific architectural styles (Figure 3.24)[392], combining them to create more complex models that have various architectural references. Rendered images were then used as a database for GAN. The image results were presented in environments according to their concepts (Figure 3.25).[393]

[392] Henan Liu, Longtai Liao, and Akshay Srivastava, "An Anonymous Composition: Design Optimization Through Machine Learning Algorithm," in *Ubiquity and Autonomy - Paper Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2019, 404–411* (CUMINCAD, 2019), http://papers.cumincad.org/cgi-bin/works/Show&_id=caadria2010_044/paper/acadia19_404.
[393] Liu, Liao, and Srivastava.



Figure 3.24 : The library created by the Generative Model Script. Source: Liu, H., Liao, L., & Srivastava, A. (2019). An Anonymous Composition Design Optimization Through Machine Learning Algorithm. *Ubiquity and Autonomy - Paper Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2019*, 404–411.



Figure 3.25 : Post-Production of the output configurations. Source: Liu, H., Liao, L., & Srivastava, A. (2019). An Anonymous Composition Design Optimization Through Machine Learning Algorithm. *Ubiquity and Autonomy - Paper Proceedings of the 39th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2019*, 404–411.

In another study, Wenzhe Peng, Fan Zhang, and Takehiko Nagakura worked on a dataset (Figure 3.26), including parts of 3-D models to decode architectural space

using Machine Learning and Computer Vision.[394] These models were the buildings of renowned architects. It was expected to recognize specific local compositions in these partial models to produce new compositions. Images of model parts were used for training a Neural Network, and new 3-D configurations were created by post-processing on 2-D output.[395]

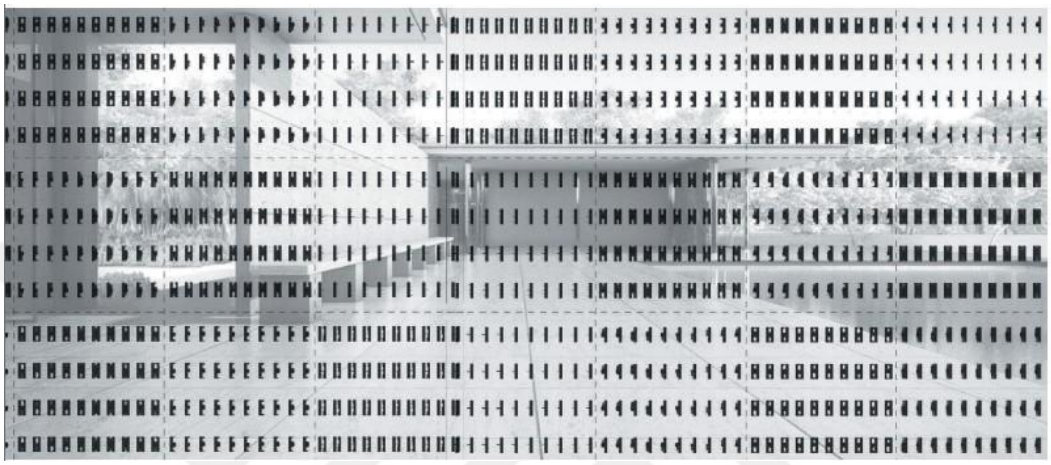


Figure 3.26: Decoding architectural space using machine-learning and computer vision. Source: Peng, W., F. Zhang, and T. Nagakura. 2017. "Machines' Perception of Space. Disciplines and Disruption." Proceedings Catalog of the 37th Annual Conference of the Association for Computer Aided Design in Architecture, ACADIA 2017.

[394] Wenzhe Peng, Fan Zhang, and Takehiko Nagakura, "Machines' Perception of Space: Employing 3D Isovist Methods and a Convolutional Neural Network in Architectural Space Classification," in *ACADIA 2017: DISCIPLINES & DISRUPTION [Proceedings of the 37th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA) ISBN 978-0-692-96506-1] Cambridge, MA 2-4 November, 2017), Pp. 474- 481* (CUMINCAD, 2017), http://papers.cumincad.org/cgi-bin/works/BrowseTree=series:acadia+year:2011/Show?acadia17_474.

[395] Peng, Zhang, and Nagakura.

3.6 Volumetric Deep Learning to Transform Design Data

In voxel methods for 3-D Deep Learning models, a new dimension is added to pixels (2-D images) to produce voxels.[396] There are significant advances nowadays in volumetric Deep Learning for shapes, such as 3D-GAN that use the 3-D CNNs for understanding shapes and generating models (Figure 3.27) or part-based approaches that reconstruct parts based on 3-D Deep Learning.[397]

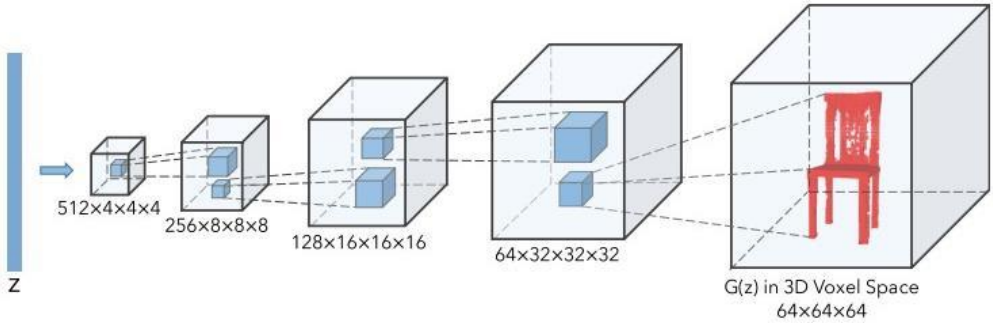


Figure 3.27: The generator in 3D-GAN. Source: Wu, J., Zhang, C., Xue, T., Freeman, W. T., & Tenenbaum, J. B. (2016). Learning a probabilistic latent space of object shapes via 3D generative-adversarial modeling. *Advances in Neural Information Processing Systems*, *Nips*, 82–90.

But in volumetric Deep Learning, the resolution is always low because the procedure that would complete easily in 2-D does not work as well in 3-D. Images contain information in every pixel, while most of the voxels are empty and redundant when representing a shape in 3-D. Another approach for 3-D Deep Learning models is based on point clouds. Unlike the voxels that emerge from structurally positioned 3-D pixels, point clouds are almost in a random distribution, and they have no structure or connectivity. Point clouds are a set of unstructured points in a 3-D

[396] Zhijian Liu et al., "Point-Voxel CNN for Efficient 3D Deep Learning," *ArXiv:1907.03739 [Cs]*, December 9, 2019, http://arxiv.org/abs/1907.03739.
[397] Wu et al., "Learning a Probabilistic Latent Space of Object Shapes via 3D Generative-Adversarial Modeling."

coordinate system that represent real-world 3-D objects.[398] It is mostly used in robotic applications and 3-D scanners like LiDAR.[399] It is the most used capturing technique to digitalize real-world structures.[400] The first paper that shows point clouds in Deep Learning is PointNet, presented at the IEEE conference in 2007 (Figure 3.28).[401] The CriticalSet in the PointNet shows that the outline of each shape is enough to represent the shape with the critical set of points.[402] There exist extensive sources on point clouds for different tasks, such as shape generation using spatially positioned point clouds[403] or the learning representations and generative models for 3-D point clouds[404], which inspired the methodology of the present Extended Cognition research.

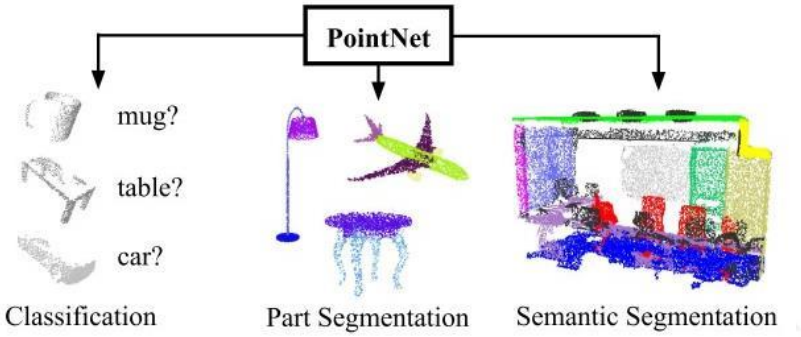


Figure 3.28: Applications of PointNet. Source: Qi, C. R., Su, H., Mo, K., & Guibas, L. J. (2017). PointNet: Deep learning on point sets for 3D classification and segmentation. *Proceedings - 30th IEEE Conference on Computer Vision and Pattern Recognition, CVPR 2017*, *2017-Janua*, 77–85. https://doi.org/10.1109/CVPR.2017.16

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[398] Liang Cheng et al., "Registration of Laser Scanning Point Clouds: A Review," *Sensors* 18, no. 5 (May 2018): 1641, https://doi.org/10.3390/s18051641.
[399] Cheng et al.
[400] Cheng et al.
[401] Charles R. Qi et al., "PointNet: Deep Learning on Point Sets for 3D Classification and Segmentation," *ArXiv:1612.00593 [Cs]*, April 10, 2017, http://arxiv.org/abs/1612.00593.
[402] Qi et al.
[403] Matheus Gadelha, Subhransu Maji, and Rui Wang, "Shape Generation Using Spatially Partitioned Point Clouds," *ArXiv:1707.06267 [Cs]*, July 19, 2017, http://arxiv.org/abs/1707.06267.
[404] Panos Achlioptas et al., "Learning Representations and Generative Models for 3D Point Clouds," *ArXiv:1707.02392 [Cs]*, June 12, 2018, http://arxiv.org/abs/1707.02392.

Volumetric Deep Learning methods have been applied in studies searching for alternative formal representations in the field of design. In one such study, Yubei Song, Yiying Tang, and Maksim Drapey (2020) developed a project working completely in a 3-D environment.[405] For this project, a dataset of 2000 concert halls was produced (Figure 3.29). The aim was to reach the interpretation of the designed neural network on acoustic spaces by analyzing the new generations of designed Machine Learning model. Meshes of concert hall models were used to train Graph Convolutional Neural Network (CNN) (Figure 3.30). An AI model generated alternative formal representations of concert halls with acoustical features, which were also analyzed via simulation tools (Figure 3.31). Then, a sense of interior space within mesh models was created by Graph CNN (Figure 3.32).[406]

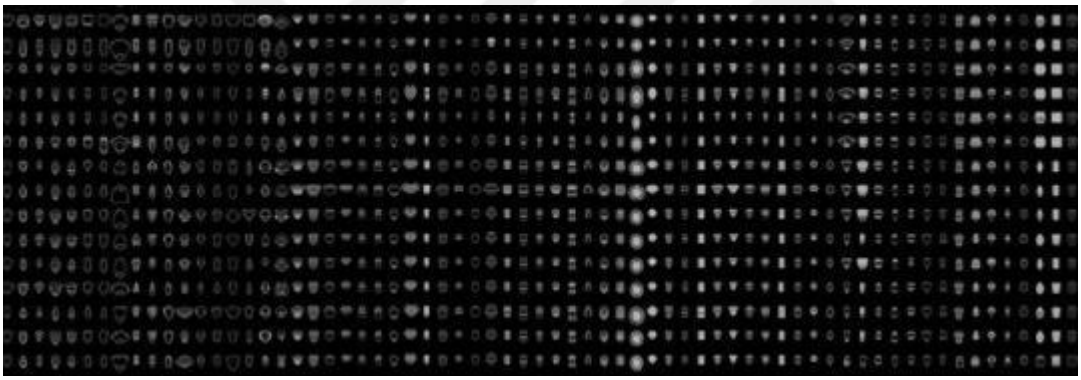


Figure 3.29: Data set of Concert Halls' 3D Models. Source: "Adaptive Acoustic". Web. 9 December 2021. <https://taubmancollegethesis.com/TEXT_Yubei-Song-Yiying-Tang-Maksim-Drapey>.

[405] Yubei Song, Yiying Tang, and Maksim Drapey, "Adaptive Acoustic" (Taubman College, 2020), https://taubmancollegethesis.com/TEXT_Yubei-Song-Yiying-Tang-Maksim-Drapey.
[406] Song, Tang, and Drapey.

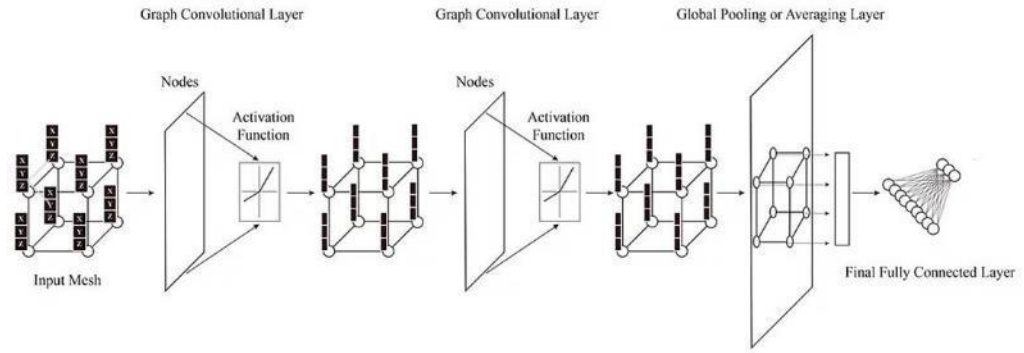


Figure 3.30: The internal process of Graph Convolutional Neural Network. Source: "Adaptive Acoustic". Web. 9 December 2021. <https://www.adaptiveacoustic.com/>.

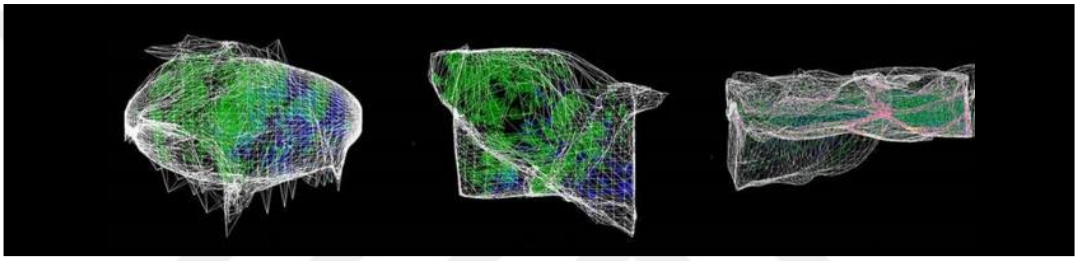


Figure 3.31: The outputs on Graph CNN operated by simulation tools. Source: "Adaptive Acoustic". Web. 9 December 2021.<https://www.adaptiveacoustic.com/>.

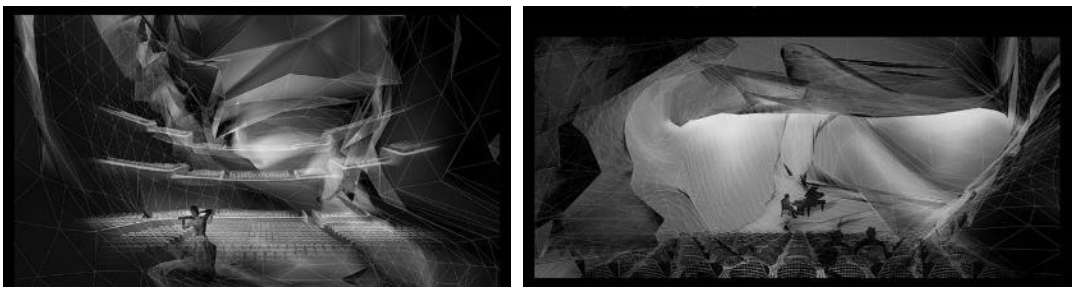


Figure 3.32: The views from interior space. Source: "Adaptive Acoustic". Web. 9 December 2021. <https://www.adaptiveacoustic.com/>.

Another study developed by Ardavan Bidgoli and Pedro Veloso processes point cloud data for the generation of 3-D models. Bidgoli and Veloso used an Autoencoder for point clouds to provide new generations of 3-D models (Figure 3.33).[407] They mentioned the advantages of using point cloud for 3-D representations in Machine Learning because it allows producing samples both by using a digital model and scanning physical objects using LiDAR Scanners.[408]

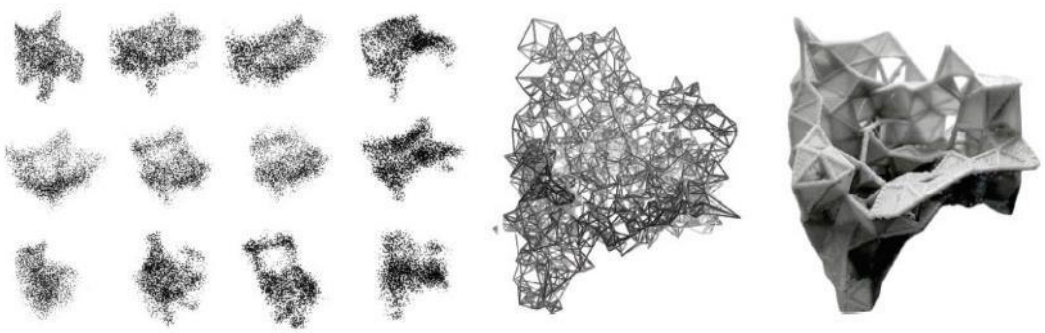


Figure 3.33: Chairs generated using DeepCloud; and 3D-printed chair with lower resolution. Source: Bidgoli, A., & Veloso, P. L. A. (2018). DeepCloud. In *Recalibration: On imprecision and infidelity Paper proceedings book for the 2018 Association of Computer Aided Design in Architecture Conference*.

In the next chapter, the project developed as part of this present thesis research is demonstrated. This project aims at adding new layers to information processing through transformations and operations of real-world structures. In this project, alternative representations of the physical structure in the external world through

[407] Ardavan Bidgoli and Pedro Veloso, "DeepCloud. The Application of a Data-Driven, Generative Model in Design," in *ACADIA // 2018: Recalibration. On Imprecisionand Infidelity. [Proceedings of the 38th Annual Conference of the Association for Computer Aided Design in Architecture (ACADIA) ISBN 978-0-692-17729-7] Mexico City, Mexico 18-20 October, 2018, Pp. 176-185* (ACADIA, CUMINCAD, 2018), http://papers.cumincad.org/cgi-bin/works/paper/acadia18_176.
[408] Bidgoli and Veloso.

design data are produced for the discovery of possible extensions of design cognition. Various datasets are generated based on the theoretical approach of the research using the 3-D point cloud model of the physical structure created with LiDAR Scanner and mesh models. In the processing of these data, experiments are conducted based on the multi-stage nature of information processing systems and the computational approach to vision, as well as the transformation of physical structures proposed in the Extended Cognition Hypothesis. Alternative 3-D models are then created through Deep Generative Models to be used as a design vocabulary for combinatorial formations.

CHAPTER 4

PROJECT

The approach underlying this research is experienced in a project developed by the author in collaboration with Dr. Cihan Öngün.[409] This project[410] creates a platform for the qualitative examination of the hypothesis, assuming that it is possible to decode and use the cognitive information of an architectural structure, which is an external world structure that carries the information about the cognitive processes, for investigating the extensions of design cognition.

The data collection for the project is conducted from primary sources of the chosen context, The Faculty of Architecture at METU[411]. Original drawings of the chosen context are provided by the METU Directorate of Construction and Technical Services. The LiDAR Scanner model was developed by the Photogrammetry Laboratory of the Faculty of Architecture at METU[412], and mesh models are our own production.

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[409] Dr. Cihan Öngün is a Senior Deep Learning Engineer at Signatrix GmbH. He received his Ph.D. from Information Systems Department at Graduate School of Informatics, Middle East Technical University. His research interests include Generative Models, Computer Vision**,** 3-D Perception, Machine Learning and Deep Learning. He worked as research and teaching assistant during his graduate studies and was the coordinator of Deep Learning and Computer Vision Lab in his department.

[410] ARCH 585 / CODEREL inspired the intellectual and technical development of this study.

[411] METU Faculty of Architecture is designed by Behruz Çinici and Altuğ Çinici, who won the competition opened for the METU campus and buildings in 1961.("Orta Doğu Teknik Üniversitesi (ODTÜ) Mimarlık Fakültesi," Arkiv, accessed January 7, 2022, http://www.arkiv.com.tr/proje/ortadogu-teknik-universitesi-mimarlik-fakultesi/7915)

[412] Drawings of METU Faculty of Architecture have been provided by the METU Directorate of Construction and Technical Services. In the experiments, a LiDAR scanner model developed by

4.1 Background

4.1.1 Cognitive Systems and Computational Approach to Vision

The present research adopts a computational approach in Extended Cognition research. The approaches in cognitive science explaining the relationship between the human mind and environmental data are investigated. Computational methods for vision in cognitive sciences are examined as well as the relationship of these methods with Artificial Neural Networks, the specific methodology used in this research.

A cognitive system cannot develop without a physical embodied action world;[413] hence cognition is inseparable from bodily action: The cognitive system constructs and develops its own understanding of the world in which it is embedded, that is, its own agent-specific and body-specific knowledge of its world. In the Extended Cognition Hypothesis, developed by Clark and Chalmers,[414] the mind is not just limited by being embedded in the body, but it also has a relation with the environment. According to Clark and Chalmers,[415] the environmental object is a part of the mind. The mind, body, and environment are inseparable and act together to create a cognitive system; in that sense, the mind is extended into the physical world.[416] This hypothesis states that extended cognition includes external objects that act according to the aims of internal processes. In this study, the use of point cloud

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Kemal Gülcen at the Photogrammetry Laboratory of the Faculty of Architecture has been used (courtesy of Prof. Dr. Neriman Şahin Güçhan, dean of the Faculty of Architecture).

[413] David Vernon, *Artificial Cognitive Systems: A Primer* (Cambridge, MA: The MIT Press, 2014).

[414] Clark and Chalmers, "The Extended Mind."

[415] Clark and Chalmers.

[416] Lotte Meteyard et al., "Coming of Age: A Review of Embodiment and the Neuroscience of Semantics," *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior* 48, no. 7 (July 2012): 788–804, https://doi.org/10.1016/j.cortex.2010.11.002.

data in the 3-D context to design rational agents via AI applications that are parts of cognitive systems is related to this approach. Since the information in 3-D context contains the rational decisions of the human mind, and the 3-D model is the last level of visual processing, depending on the levels of analysis approach of Marr,[417] this data can be expected to be decoded by AI systems to design new agents learning from the architectural context.

Marr[418] explains vision as an information processing system that has levels of analysis. In another study, Marr[419] applies this approach to human early vision via feature-detection/pattern recognition. According to him, vision is described as a transition from a 2-D visual system on the retina to a 3-D representation. These stages of vision include a primal sketch, which is the feature detection of main components of the environment like edges, lines, groups, 2.5-D sketch where the contours, textures are identified, and 3-D sketch where the environment is visualized as a 3-D model.[420]

Artificial Neural Networks are inspired by the principles of the brain, performing a specific task.[421] When human vision is considered for observing the working system of Neural Networks, it is possible to relate Artificial Neural Networks and Marr's approach. The action is the output of a Neural Network that responds to a defined set of inputs, and Artificial Neural Networks are the representation of this information process. In Artificial Neural Networks, there are inputs from the body and environment for certain tasks and goals related to specific problems, as in Marr's computational level. These input signals are processed via various weights by

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[417] Marr and Poggio, "From Understanding Computation to Understanding Neural Circuitry."
[418] Marr and Poggio.
[419] Marr, *Vision*.
[420] Marr.
[421] Friedenberg and Silverman, *Cognitive Science*.

transmitting between neurons according to certain biases and various activation functions that are the network architectures or the pattern of nodes between them. This process has a relation with the algorithmic level of Marr. After processing the information in hidden layers of Artificial Neural Networks, there is an output layer that represents the realization of the process, like the implementation layer in Marr's approach.

4.1.2 3-D Deep Generative Models

Generative Adversarial Networks (GANs)[422] are one of the state-of-the-art Deep Generative Models and are highly used in all kinds of generative tasks. In this research, we used a GAN to generate new samples from the learned cognitive information encoded in an architectural structure. We also used an AutoEncoder, which is an encoder-decoder model in ANNs for encoding the data into reduced dimensions and then decoding it to get the input data again. The aim is to represent the data in lower dimensions, extracting important features and learning about underlying structures in the data with minimum error, to learn and encode the common style of input samples. ANNs, which constitute the behavior-based approach in Artificial Intelligence, are designed according to strategies made on input and output as in the present research, instead of predetermined computational processes like classical information processing systems. Therefore, possible extensions of design cognition are explored in this research by adding new layers to the use of ANNs in design, including the transformation stages of design data in the external world.

[422] Goodfellow et al., "Generative Adversarial Networks."

This project experiments with the processing of the design context with AI using point cloud data directly obtained from the physical environment. Since we aim to learn from design cognition using a real-world structure, we chose to work on point clouds instead of other 3-D representation methods such as Polygonal Meshes or 3-D Voxels.

4.2 Concept

The present research aims to use the cognitive information encoded in the physical world structures to be decoded by various information processing methods to explore possible extensions and alternative representations of design cognition. In this context, the idea of Extended Cognition, which is an approach to understanding the mind in cognitive sciences discussed in the previous chapters, shapes the theoretical framework of the project. The methodology used in this project is based on Artificial Neural Networks, more specifically, Deep Generative Models. Current studies in the field are mainly based on the formal representations through the embodiment of cognitive processes. The present research makes use of non-biological resources and embodied action; that is, design data of the external world are transformed according to design references and part-whole relations, inspired by the strategies underlying computer vision as explained in the previous chapter, and datasets are created using various techniques. The use of these datasets with Deep Generative Models, which is the latest advancement in Artificial Neural Networks (ANNs), was found suitable for reasons explained in the previous chapter.

In the project described in this chapter, a detailed 3-D point cloud model is created by scanning an architectural structure with LiDAR. Then, these point cloud data and mesh models are divided into parts according to architectural references and part-whole relationships with various techniques to create datasets. A Deep Learning Model is trained using these datasets, and new 3-D models produced by Deep

Generative Models are examined. These new 3-D models, which are embodied in different representations, such as point clouds, mesh models, and bounding boxes, are used as a design vocabulary, and combinatorial formations are generated from them. Thus, it is aimed to explore possible extensions of design cognition while generating alternative representations of the physical architecture using its real-world sensory data through ANNs which is a simulated form of cognition having the ability to learn. The stages of the project are described in the workflow diagram in Figure 4.1.

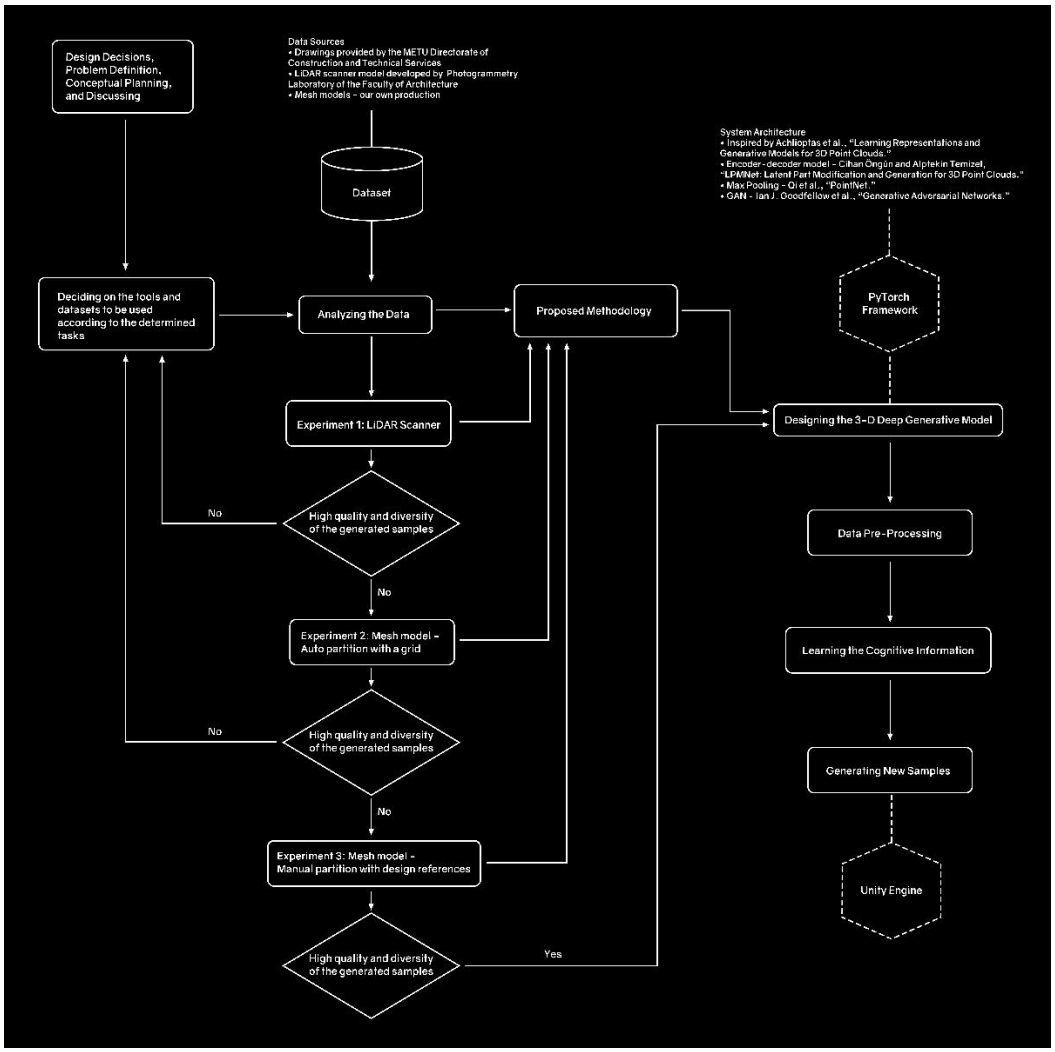


Figure 4.1: Workflow Diagram

To analyze the cognitive information in the 3-D contexts and to investigate its use for alternative representations through AI, a 3-D model is deconstructed and processed. Then the new 3-D models produced by the AI model are examined. According to the proposed hypothesis, design elements come together by conscious design decisions to provide the morphology that creates a specific character. The design, which is formed by the combination of elements, encodes the cognitive information within the whole as well as in its parts. This approach is demonstrated in Figure 4.2 to visualize the contextualization of the project regarding the transformation of cognitive information between the whole and its spatial parts.



Figure 4.2: Transformation of cognitive information between the whole and parts

Different combinations of design elements are selected, and the cognitive information in different spatial parts of the model is analyzed through 3-D Deep Learning algorithms. For this purpose, the AI model is trained by using spatial 3-D

parts of the design system to analyze the information about the whole system inside the parts. Later, a Generative Model is used to produce alternative representations reflecting extensions of design cognition. The conceptual representations of the process of designing the AI model via 3-D parts of the model and the decoding of the design system are displayed in Figure 4.3.

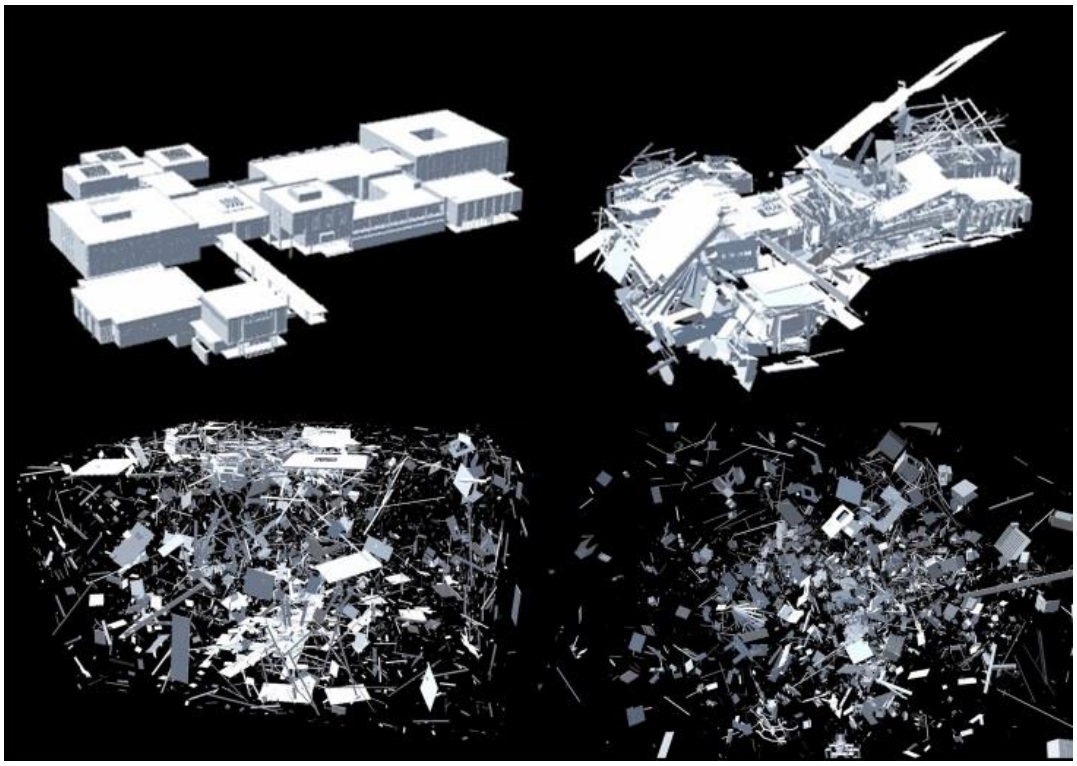


Figure 4.3: The conceptual representations of designing the AI model via 3-D parts

4.3 Context

The feature sought in the chosen context is its inclusion of meaningful and repetitive combinations of design elements that express a strong character. In this study, the METU Faculty of Architecture (Figure 4.5) is used as context. The construction of the building, designed by Behruz Çinici and Altuğ Çinici, who won the competition

opened for the METU campus and buildings in 1961, was completed in 1963.[423] METU Faculty of Architecture building that is one of the most important architectural works of the period, is located in Ankara in METU Campus, which includes the Eymir Lake on a total area of 4,500 hectares, has a construction area of 500,000 m², and has a capacity of 15,000 students.[424] The Faculty of Architecture building, which is one of the parts of the concept of faculty complexes connected to the alley designed for the METU campus plan, is the first building to be constructed in the construction process between 1961 and 1980.[425] The building is accepted to be the first building in the country to be constructed with brutalist aesthetics.[426] Spanning 13000 m², it has a complex plan, including several parts formed in an orthogonal geometry. As Wojciech Niebrzydowski and Haluk Zelef relate, the form of the building resembles a smaller version of brutalist mega-structures.[427] There is a visible and strong articulation of solids that make up the architectural composition, which is advantageous for the purposes of the study, and the required data could be obtained from primary sources.[428] The views from the 3-D mesh model of the building that is produced for the project are shown in Figure 4.4.

[423] "Orta Doğu Teknik Üniversitesi (ODTÜ) Mimarlık Fakültesi," Arkiv, accessed January 7, 2022, http://www.arkiv.com.tr/proje/ortadogu-teknik-universitesi-mimarlik-fakultesi/7915?lang=en.
[424] "Orta Doğu Teknik Üniversitesi (ODTÜ) Mimarlık Fakültesi."
[425] "Orta Doğu Teknik Üniversitesi (ODTÜ) Mimarlık Fakültesi."
[426] A. Niebrzydowski and H. Zelef, "Brutalism and METU Department of Architecture Building in Ankara," *Architecture Civil Engineering Environment*, no. Vol. 5, 2 (2012): 21–30.
[427] Niebrzydowski and Zelef.
[428] Drawings of METU Faculty of Architecture, provided by METU Directorate of Construction and Technical Services. In the experiments, LiDAR scanner model developed by Kemal Gülcen working in the Photogrammetry laboratory of the Faculty of Architecture has been used (courtesy of Prof. Dr. Neriman Şahin Güçhan, dean of the Faculty of Architecture), and mesh models of our own production have been used.

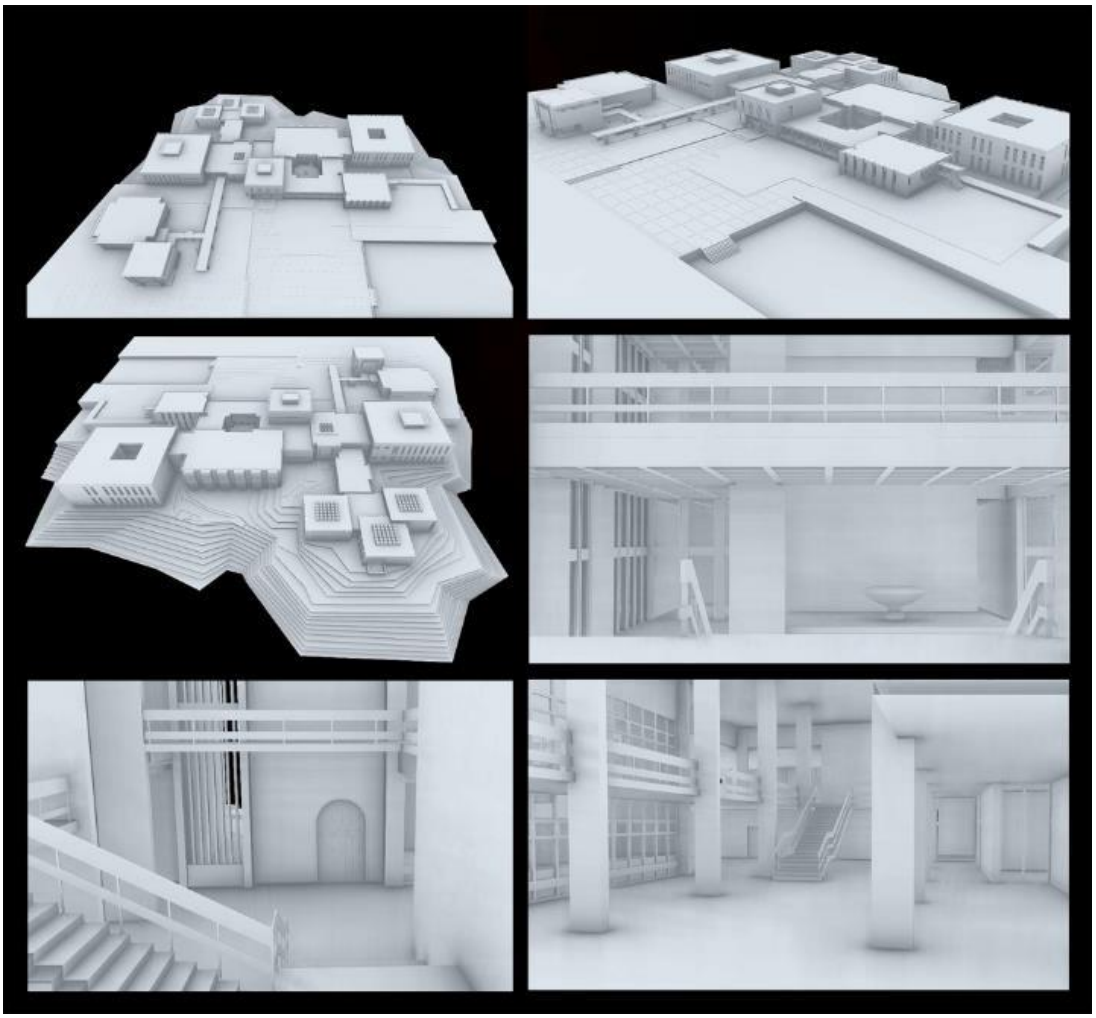


Figure 4.4: 3-D mesh model of the building

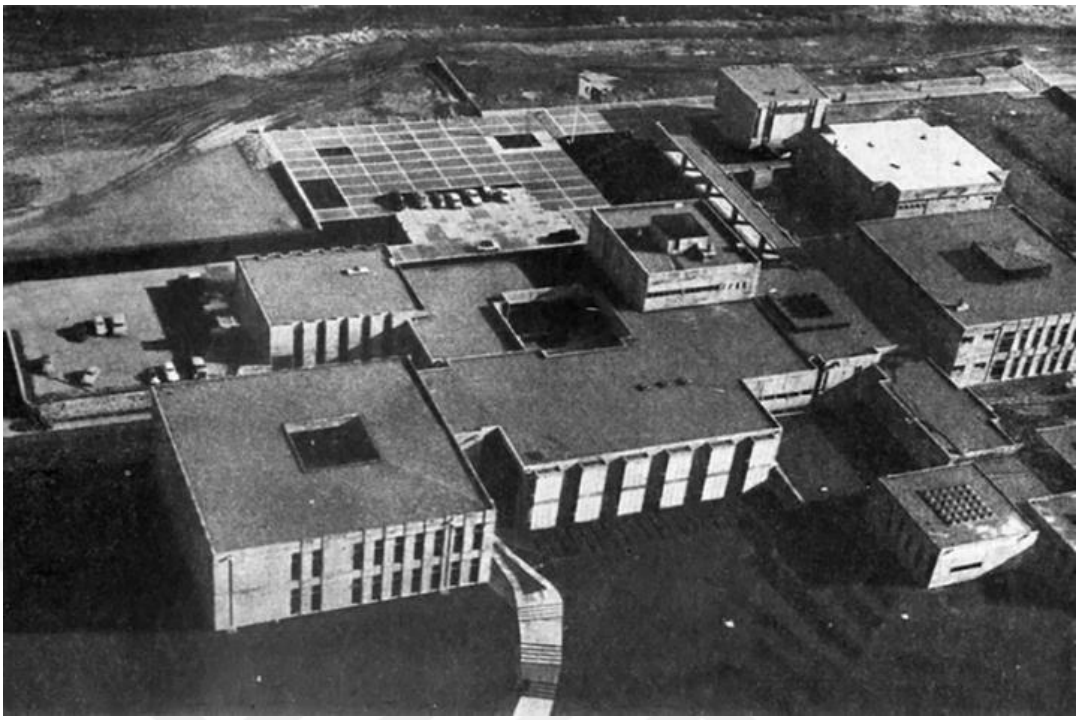


Figure 4.5: Aerial view of the building

4.4 Significance

This research is expected to provide new insights into the cognitive information within 3-D contexts to enable alternative generative design tasks through AI systems, more specifically by the use of Deep Generative Models. The study uses the building parts of an architectural context for providing the generation of a specific design vocabulary. Recent studies in the field are generally seen to bypass the information in 3-D contexts, which is difficult to collect and process, to enhance Machine Learning (ML) techniques that process mainly 2-D and abstract data such as drawings or photos. The present approach, on the other hand, focuses on the analysis of real-world data, providing for the ability to process the parts of a 3-D model with ML to make spatial generations. It uses a single real-world structure with its sensory data to investigate the possible extensions of design cognition. It, therefore, aims for

an alternative understanding of Extended Cognition using current formal strategies in design research.

4.5 Analyzing the Data

This project also has a story about its data collection and processing stages, and these stages, which lasted for months, constitute a survey process that should be explained on its own. As mentioned in previous chapters, in Extended Cognition research, the design data of the external world goes through a number of transformation stages before being processed with ANNs. Thus, the transformation and manipulation of design data is expected to add new layers to the use of information processing systems in design studies. In this project, the transformation of design data for use in information processing systems is tested with different experiments based on architectural references and volumetric relationships, inspired by the underlying principles of computer vision. According to the notion of Extended Cognition, the idea that external world objects carry information about cognitive processes and that this information can be used for alternative cognitive tasks with the transformation and manipulation of physical structures is thus experienced to discover the possible extensions to design cognition. These experiments are briefly mentioned below:

4.5.1 Experiment 1: LiDAR Scanner

The selected design context was scanned with the LiDAR Scanner tool, which uses laser pulses to detect the distance of an object's surface. In this way, a highly detailed 3-D point cloud model was created for the chosen building (Figure 4.6). LiDAR provides the coordinate values of all the details of the building in real dimensions. This data was divided into smaller 3-D sub-units that allowed for a detailed analysis

of semantic information (Figure 4.7).[429] The ML model was trained with the sub-units of this 3-D point cloud model (Figure 4.8). Using the real scans can help to decode the cognitive information about the design process and provide experimental results on real-world data.

The LiDAR data has some problems regarding the uniformity and density of the points. The point density is higher for near locations where the LiDAR device is located. This causes a non-uniform distribution of the points among the 3D model. This also creates visible dense circles around the LiDAR device on the point cloud. ML systems tend to learn dense areas better than sparse areas. Thus, it may cause problems regarding reconstruction and generation quality. An extra pre-processing step (spatially uniform point sampling) is applied to make LiDAR data more uniform.

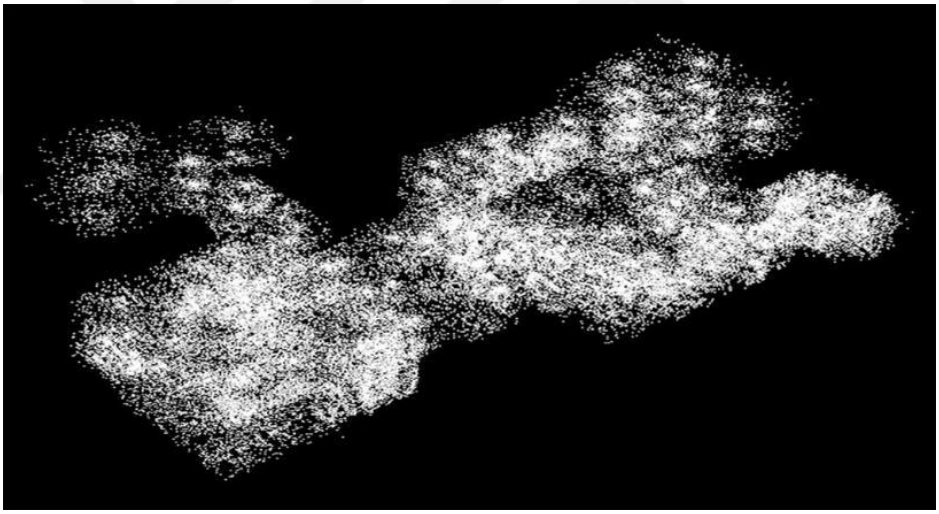


Figure 4.6: 3-D point cloud model of the selected building produced with LiDAR

[429] The term semantic is used here in the context of cognitive science, as an interdisciplinary approach to the study of meaning and mind. It covers research in philosophy, psychology, neural science, artificial intelligence, and other subject fields in cognitive science that take the relationship between meaning and mind as the main object of study (Fuyin Li (2021), Cognitive Semantics. Oxford Bibliographies. https://www.oxfordbibliographies.com/view/document/obo-9780199772810/obo-9780199772810-0279.xml).

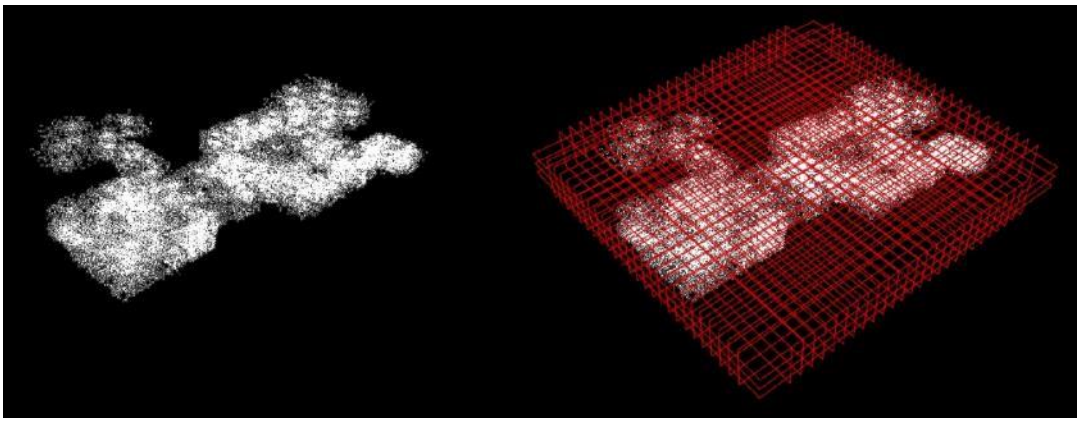


Figure 4.7: Dividing point cloud model into smaller 3-D sub-units

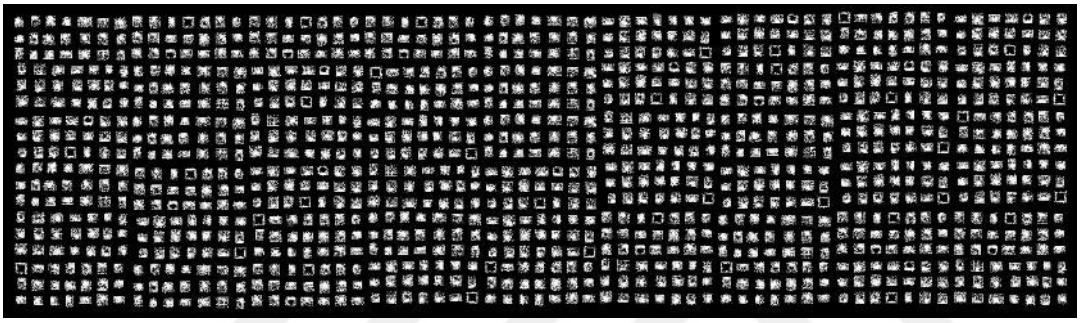


Figure 4.8: Dataset with the sub-units of this 3-D point cloud model

4.5.2 Experiment 2: Mesh model - Auto partition with a grid

At this stage, the mesh model is automatically partitioned with a 3-D grid (Figure 4.9). This is a basic process to partition the buildings with respect to the given part count. These parts are used for training the ML model (Figure 4.10). When the results are examined, some generated models are very similar or the same as some parts in the dataset. When a dataset, which consists of elements that are similar to each other, is used for training a Generative Model, the model starts to memorize the elements in the dataset and repeat them instead of understanding the hierarchical relationships of these elements and making new and different productions. Also, this automatic splitting causes unrelated and semantically unrealistic parts such as unconnected

parts or elements from different spaces. The produced parts do not follow a meaningful pattern or a useful representation. Meaning is mentioned here in the context of semantics in cognitive and computer sciences and is used in the sense of compliance with architectural references and volumetric relations. The ML model imitates the dataset by generating unconnected or meaningless parts. This method reduces the quality and diversity of the generated samples.

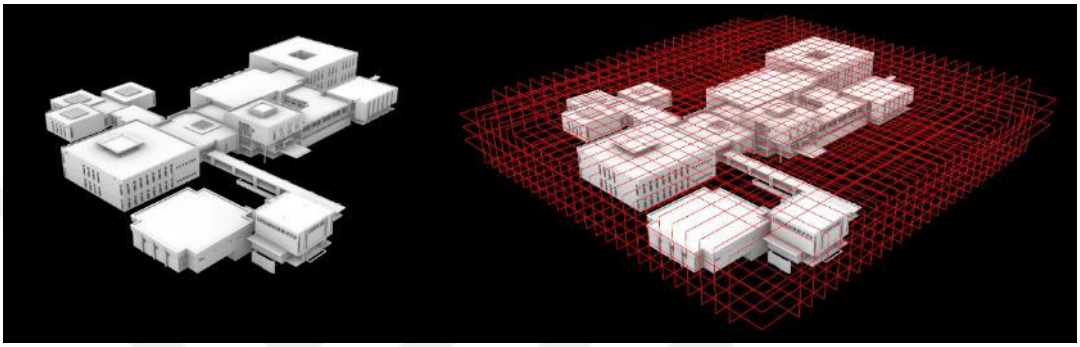


Figure 4.9: Automatically partitioned mesh model with a 3-D grid

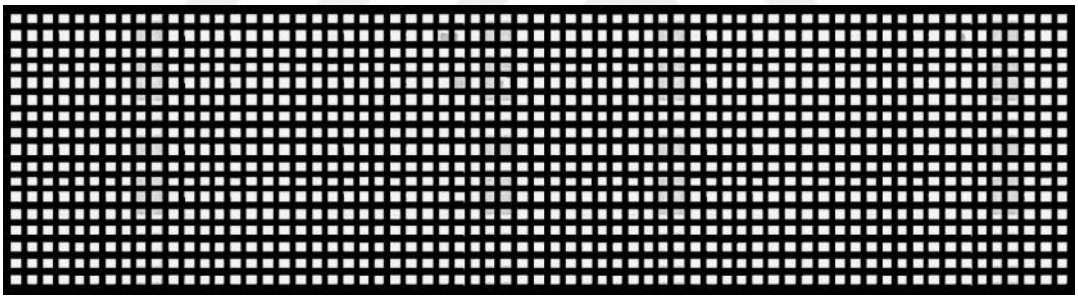


Figure 4.10: Dataset used for training the ML model

4.5.3 Experiment 3: Mesh model - Manual partition with design references

After experimenting with automatic partition, we create the dataset with logical partitions according to the references of design elements that carry the semantic representation of the design process (Figure 4.11). With this approach, the whole building is divided into parts gradually, and the results are analyzed at each stage.

First, the building is divided into 250 main parts that refer to the whole volume. Later, these 250 pieces are split into 500 pieces with references within themselves. Finally, all parts are brought together, and the parts are transformed into 1000 sub-parts containing different relational combinations to allow the machine to focus more on the details. Datasets that are gradually divided into sub-spaces according to design references are displayed in Figure 4.12. The dataset consists of both meaningful parts with a semantic representation and uniform distribution of points and surfaces.

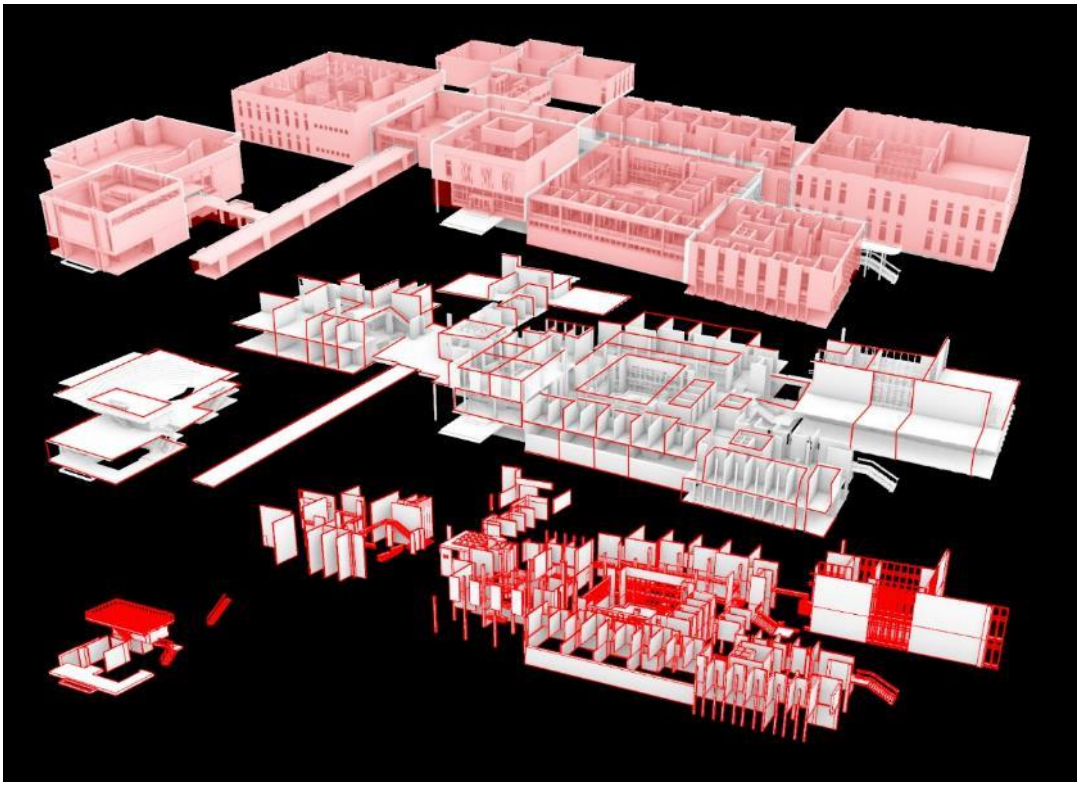


Figure 4.11: Logical partitions according to the references of design elements

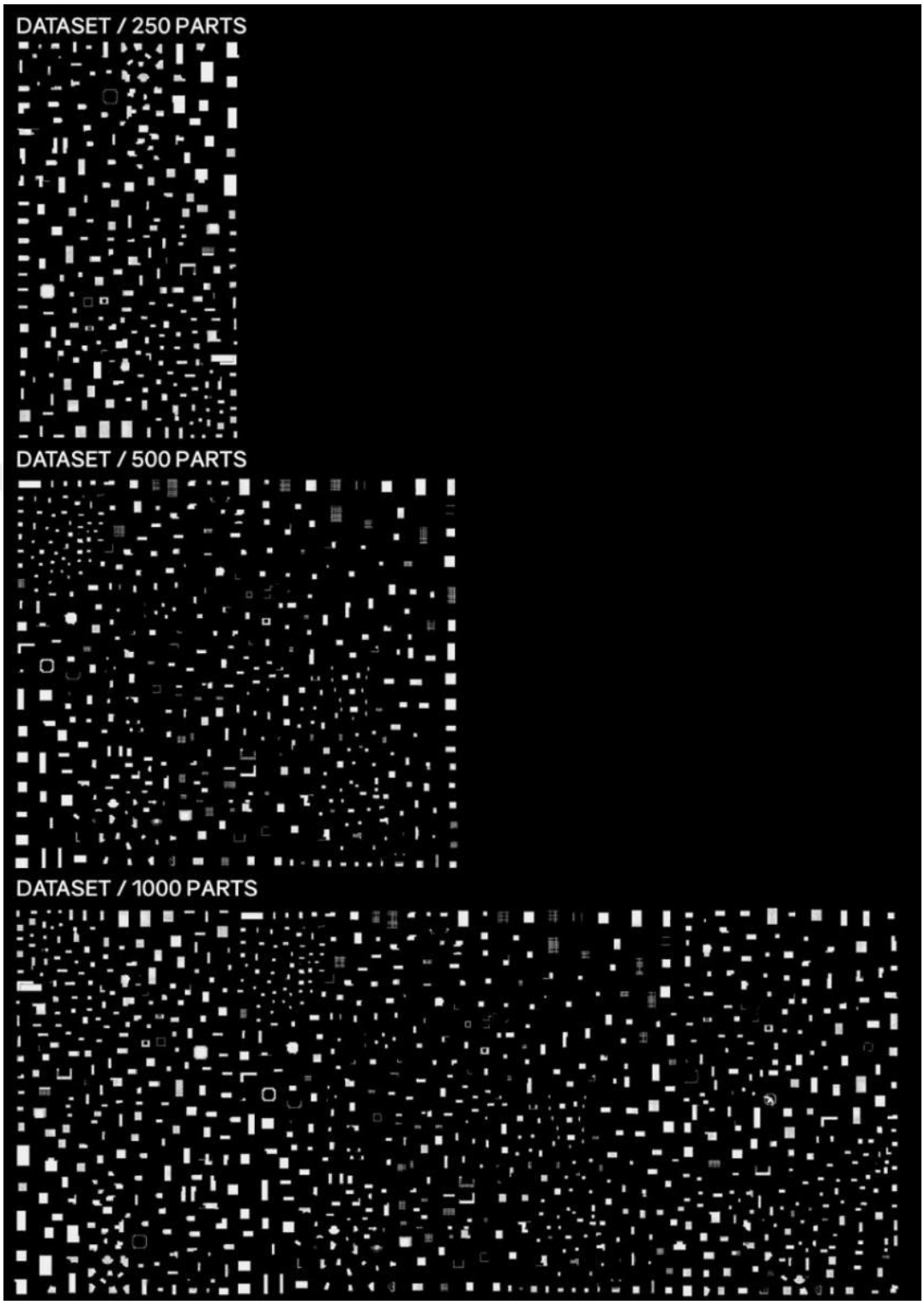


Figure 4.12: Gradually divided datasets

4.6 Methodology

The methodology of the study is inspired by Achlioptas et al.[430] First, the data is pre-processed to feed the network, as explained in Section 4.5.1 The data is fed to an encoder-decoder for learning the underlying design cognition. Then, a GAN is used to generate new samples from the learned cognitive information. The encoder-decoder and the GAN models are explained in Sections 4.5.2 and 4.5.3, respectively. All implementations are done with the PyTorch framework on an Nvidia RTX 2070 GPU and are imported into the Unity Engine. The system architecture is visualized in Figure 4.13. And the proposed methodology of the study is demonstrated in Figure 4.14.

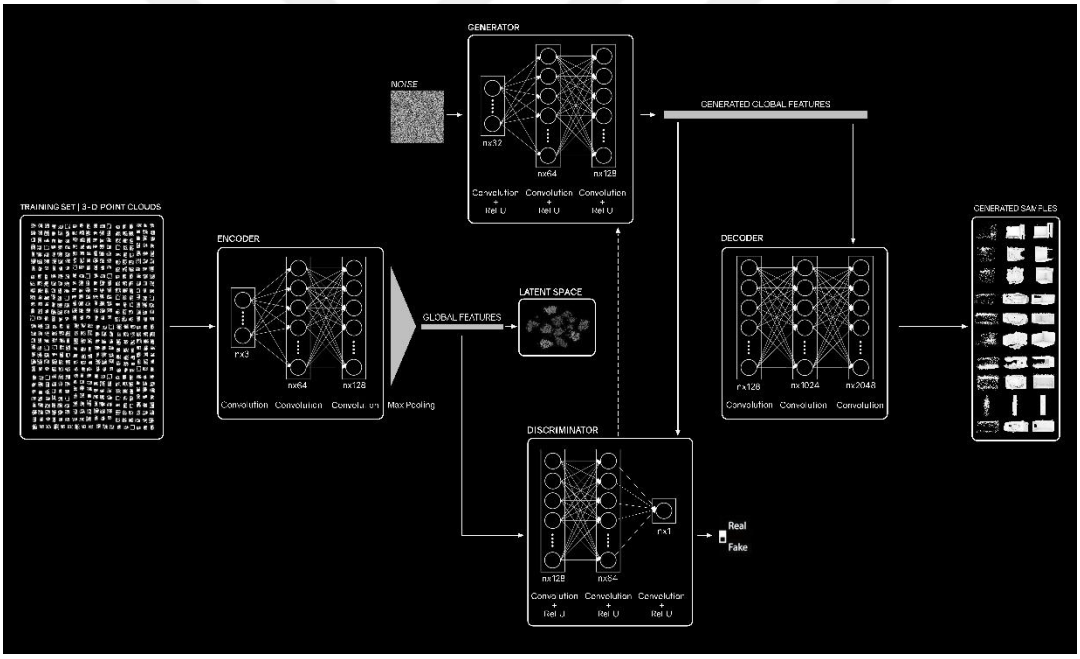


Figure 4.13: System Architecture

[430] Achlioptas et al., "Learning Representations and Generative Models for 3D Point Clouds."

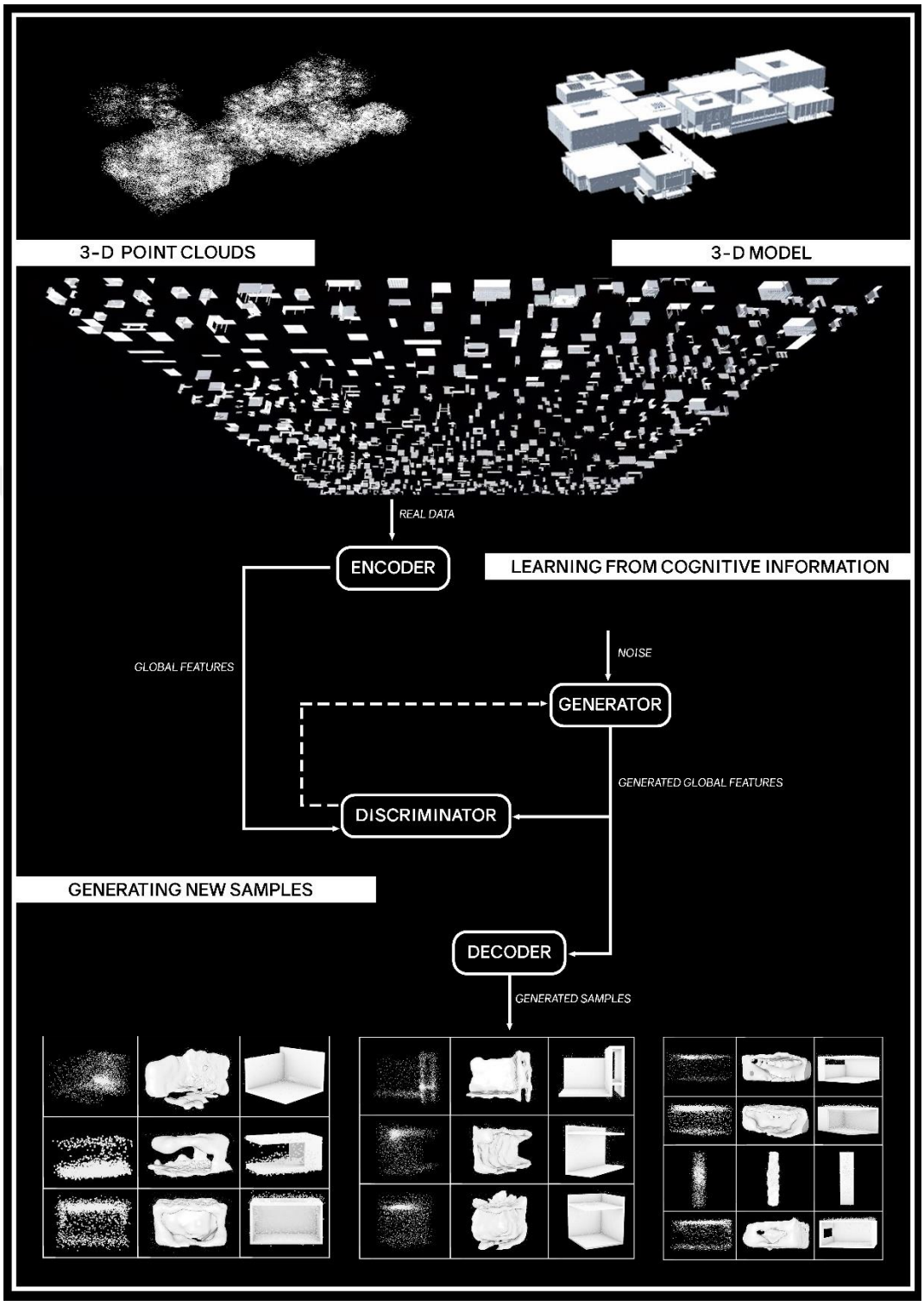


Figure 4.14: Proposed Methodology

4.6.1 Data Pre-Processing

The selected building is modeled in 3-D format. After partitioning the building model as explained in Section 4.4, there are 250, 500, and 1000 parts in 3-D mesh format for different experiments. The 3-D parts are converted into 3-D point clouds using uniform point sampling. Uniform point sampling is basically selecting a certain number of points to represent a surface. There must be at least 3 points to represent a triangle surface, and more points can be located using linear interpolation on the surface. Considering the mesh faces have different surface areas, to represent each surface uniformly, the resolution (point density) is set for each surface to its proportional area. All 3-D point cloud samples in the dataset are set to have 1024, 2048, 4096, or 8192 points for different experiments. After the conversion, all samples are positioned at the center of the coordinates and scaled into the unit cube. The dataset is randomly divided into train, validation, and test subsets with 80%, 10%, and 10% ratios, respectively.

4.6.2 Learning the Cognitive Information

Our first aim is to learn the underlying cognitive information of the design system from the dataset. An encoder-decoder model[431] (Figure 4.15) is employed to encode the real data and form a latent space that represents the design context. This latent space consists of learned features and similarities of the dataset. Since the dataset is formed from a single building, we expect the model to learn the similarities from the parts of the building.

[431] Achlioptas et al.

The encoder model[432] is inspired from the PointNet[433] referred to earlier. It is a 3-layer 1-D convolutional network with feature sizes (3, 64, 128). It extracts the features for each point having three dimensions for the x, y, and z-axes. Then a max-pooling is applied as explained in PointNet [434] to extract the global feature (code) that represents the point cloud model. The input and feature transform subnetworks are omitted since the input data is already aligned and scaled. All extracted global features form a latent space that represents the underlying style and similarities of the dataset.

The global features are then decoded using a 3-layer Fully Connected Network (128, 1024, 2048). The reconstruction loss[435] is calculated with Chamfer Distance[436] between the real and reconstructed point clouds. The network is trained end-to-end using Adam optimizer [437] with the reconstruction loss and a learning rate of $5x10^{-4}$

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[432] Cihan Öngün and Alptekin Temizel, "LPMNet: Latent Part Modification and Generation for 3D Point Clouds," *Computers & Graphics* 96 (May 2021): 1–13, https://doi.org/10.1016/j.cag.2021.02.006.

[433] Qi et al., "PointNet."

[434] Qi et al. The network takes n points as input, applies input and feature transformations, and then aggregates point features by max pooling, which is a symmetric function to aggregate information from all the points.

[435] Wei et al., "Variations in Variational Autoencoders - A Comparative Evaluation." Reconstruction loss is the loss function that is used to train an Autoencoder. it is a control of how properly the output has been reconstructed from the input.

[436] Haoqiang Fan, Hao Su, and Leonidas Guibas, "A Point Set Generation Network for 3D Object Reconstruction from a Single Image," in *2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR)* (2017 IEEE Conference on Computer Vision and Pattern Recognition (CVPR), Honolulu, HI: IEEE, 2017), 2463–71, https://doi.org/10.1109/CVPR.2017.264. The Chamfer distance is a distance metric for point sets and can be used as the loss function. For each point, the algorithm of Chamfer distance finds the nearest neighbor in the other set and sums the squared distances up to produce reasonable high-quality results in practice.

[437] Diederik P. Kingma and Jimmy Ba, "Adam: A Method for Stochastic Optimization," *ArXiv:1412.6980 [Cs]*, January 29, 2017, http://arxiv.org/abs/1412.6980. Adam is an algorithm for first-order gradient-based optimization of stochastic objective functions, based on adaptive estimates of lower-order moments.

for 1000 epochs. The reconstruction loss is around $10x10^{-4}$, which indicates a good reconstruction performance with minimal error.

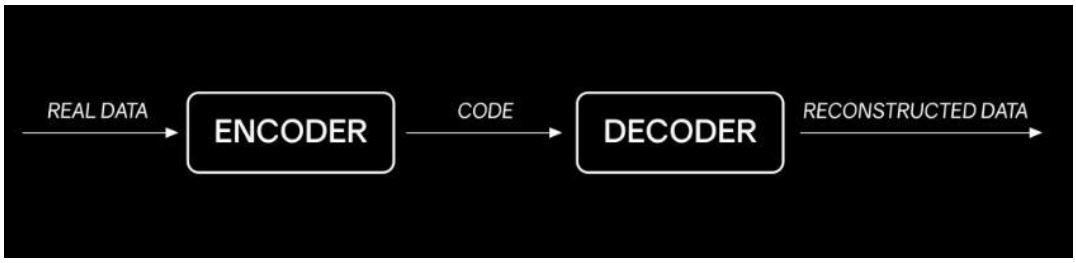


Figure 4.15: The AutoEncoder model

4.6.3 Generating New Samples

A GAN (Figure 4.16) is employed for generating new samples in the learned cognitive information. The extracted global features (codes) are fed to the GAN to generate new global features. The generated global features are then decoded using the trained decoder to get 3-D point clouds that represent the real-world data.

Both the Generator and the Discriminator are 3-layer Fully Connected Networks with (32, 64, 128) and (128, 64, 1) sizes, respectively. All layers have ReLU activation functions followed by batch normalization layers except the output layers. The Generator input is sampled from a Normal distribution. A WGAN [438] objective function is used for training with better stability and diversity. Adam optimizer with learning rates of $5x10^{-4}$ and $1x10^{-4}$ is used for Generator and Discriminator, respectively.

[438] Arjovsky, Chintala, and Bottou, "Wasserstein Generative Adversarial Networks."

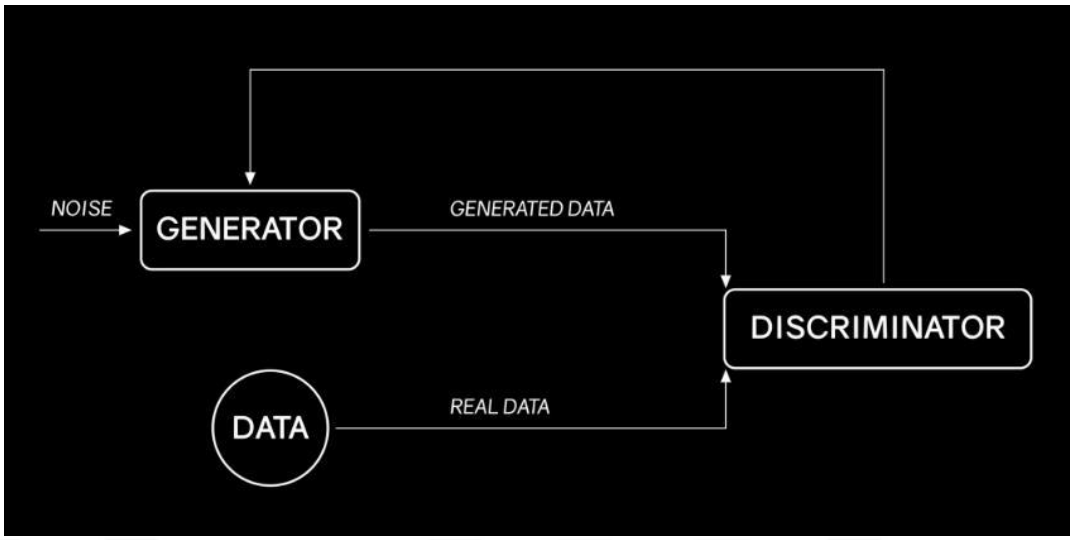


Figure 4.16: The Generative Adversarial Network (GAN) model

4.7 Results

The project developed as part of this present research provides an investigation for extending an understanding of spatial cognition problematized within the human-machine interface. It explores the possible extensions of design cognition by decoding and learning from the physical environment. This project aims at adding new layers to information processing through transformations and operations of real-world structures.

The data used in the study is collected from a built structure with a LiDAR Scanner and produced as a 3-D mesh model. This data is fed to an Artificial Neural Network to learn the underlying structure after experimenting with various transformation stages. Then a Generative Model is used to generate new elements through the learned cognitive information encoded in the physical structure. The generated samples can be analyzed in different forms, such as point clouds and 3-D meshes. The results show that the generated samples are meaningful for creating a vocabulary through the parts of the design to produce extended combinatorial formations by the

AI model. The research hence contributes to an understanding of possible extensions of design cognition within the physical structures. The 3-D Generative Model trained with partial built-in data can produce new spatial formations with the help of Artificial Neural Networks. The generated samples can be seen in Figures 4.17 and 4.18. The generated data is visualized in raw point cloud form first. Then the generated point clouds are transformed to mesh form with Poisson Surface Reconstruction[439] to analyze the surfaces and the general connected structure of the data. Later the surfaces are manually processed and flattened to analyze and use a variety of spatial representations at different abstraction levels.

It can be observed that new samples are generated with alternative formations without copying the training set, and productions have alternative structural forms within the same distribution as the training data. Also, the generated data is meaningful; that is, it has a relation with the real-world data and is useful for our purposes. The spatial configurations of the generated samples can create various scenes, as demonstrated in Figure 4.19. Since the generated forms follow the extensions of design cognition of the chosen context, they can be used as a vocabulary to produce new combinatorial formations while preserving semantics. We aim to extend this study by experimenting with various structures to provide a better analysis of the capabilities of the proposed model. Also, manual pre-processing and post-processing steps can be automated using different approaches after experimenting and analyzing the results of these approaches.

[439] Michael Kazhdan, Matthew Bolitho, and Hugues Hoppe, "Poisson Surface Reconstruction," n.d., 10. Surface reconstruction from oriented points can be cast as a spatial Poisson problem. Poisson formulation considers all the points at once, without resorting to heuristic spatial partitioning or blending, and is therefore highly resilient to data noise.

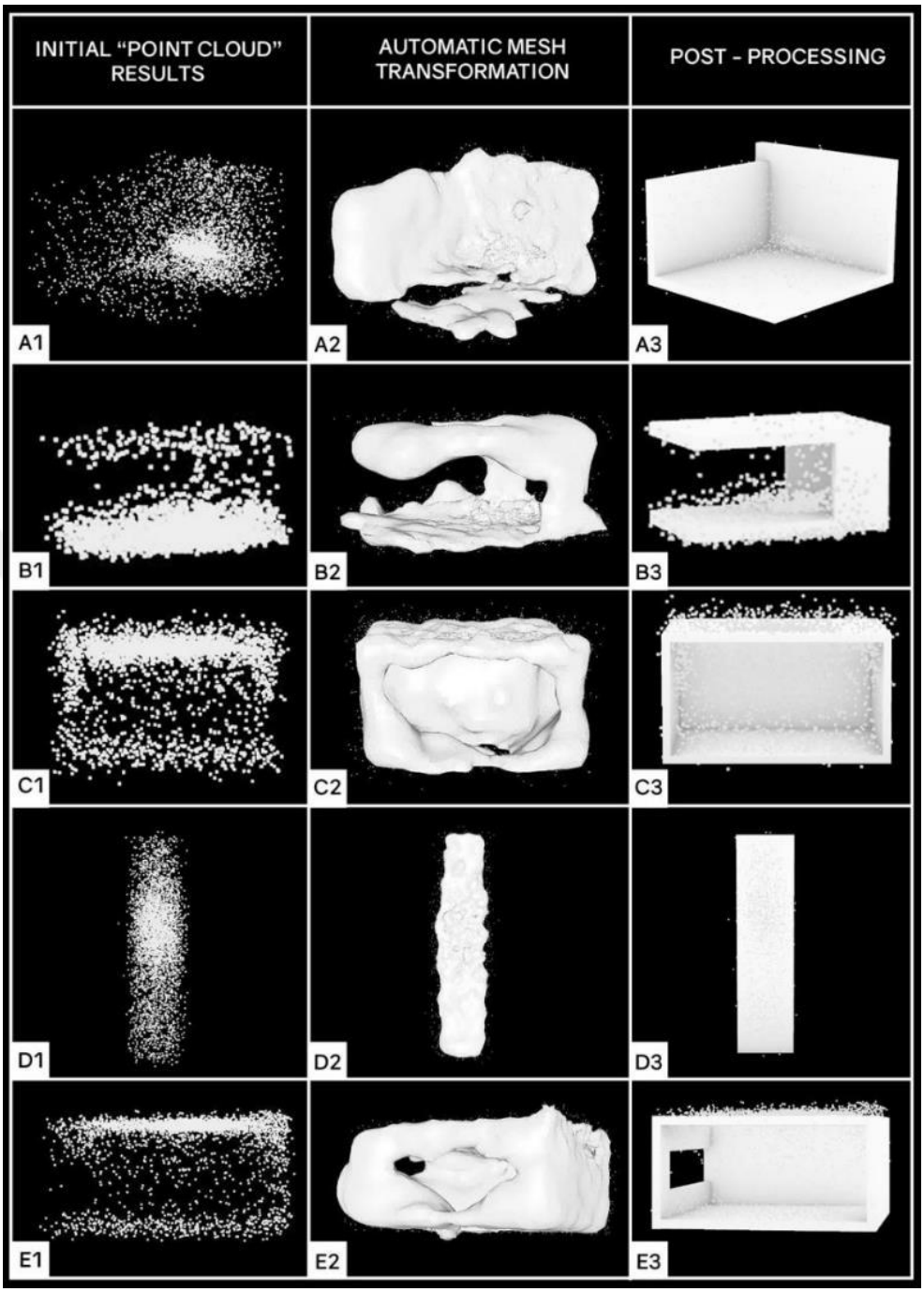


Figure 4.17: 3-D productions of the AI model embodied in different abstraction levels

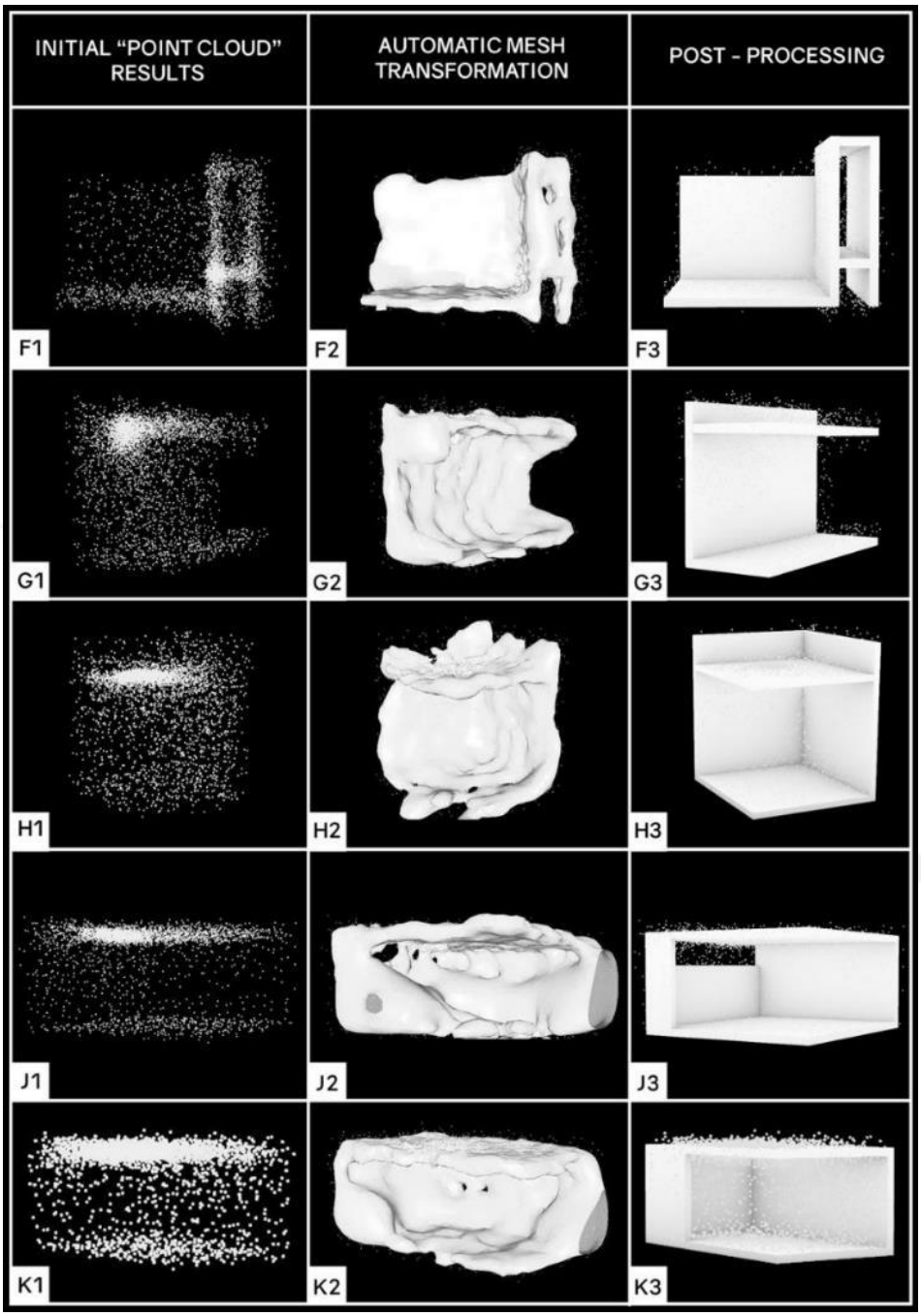


Figure 4.18: 3-D productions of the AI model embodied in different abstraction levels

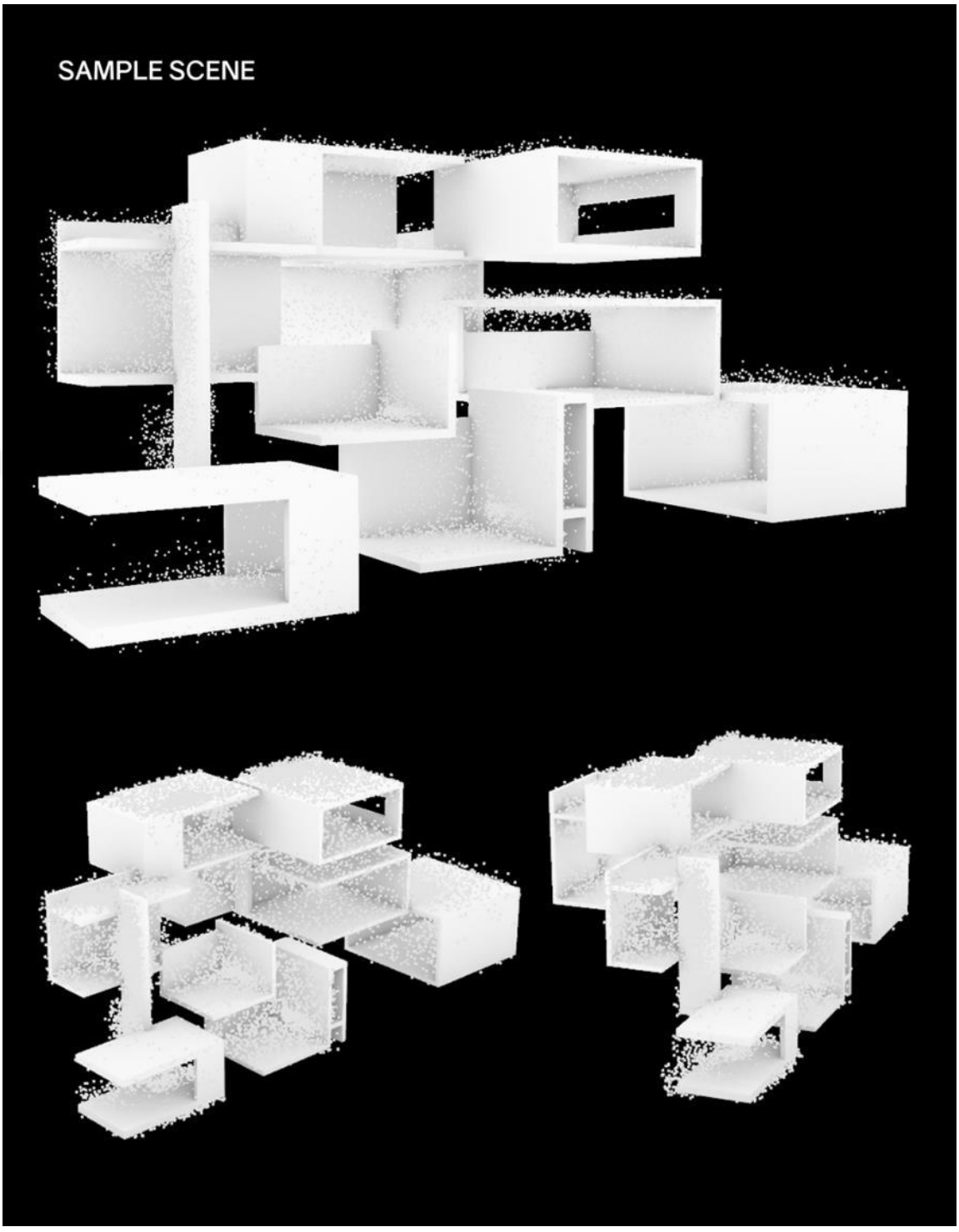


Figure 4.19: A Sample scene, with spatial configurations of the productions

CHAPTER 5

CONCLUSION

Advancements in neuroscience, computer science, and cognitive science are extending representations to formalize cognitive and mental tasks. This thesis scrutinized the notion of Extended Cognition both in its computational context and its phenomenological context in 20th century design studies.

In the methodology established to consider Extended Cognition in computational design, Computer Vision and Generative Deep Learning methods were investigated. In this way, the thesis explored possible extensions of design cognition by transforming the cognitive information encoded in the physical architecture to produce alternative representations. Thus, the research aimed at a reconsideration of Extended Cognition which had disappeared together with the counterculture in which it had flourished and shifted to cognitive science. This shift offering an alternative cognitive domain was examined for problematizing this thesis.

In the context of this problematization, the hypothesis of the thesis has been that it is possible to decode and use the cognitive information of the material architectural object, which is an external world structure that carries the information about the cognitive processes, for investigating the extensions of design cognition.

This thesis aimed at answering the following questions while examining the hypothesis:

-What data types and representations of physical structure can be used for the analysis of the cognitive information contained within the structure?

-How should architectural structures be transformed while creating data sets in order to decode the cognitive information of designers in the physical world structures?

-What are the information processing models suitable for decoding the information of design cognition in physical structure?

-How can information processing models designed with this approach be used in the production of alternative representations through the extension of design cognition?

For examining the research questions, the thesis has explored the systematic approaches and methodologies in Extended Cognition research, such as the underlying principles of and developments in Computer Vision. To examine the most recent advancements in computer vision simulations, Artificial Neural Networks (ANNs), a simulated form of cognition, has been investigated by considering its behavior-based and brain-like nature in Extended Cognition research. ANNs are not designed with predefined rules and theories like knowledge-based AI, instead they explore the way of computation themselves according to defined strategies related to inputs and outputs. The methodology of the thesis was related with transforming input-output representations of data with certain strategies based on information processing and computer vision to extend design cognition. Therefore, the nature of ANNs was found appropriate for a reconsideration of Extended Cognition within the computational design paradigm.

Also, the thesis required exploring the generation tasks in ANNs for representing the alternative formalizations by cognitive extensions within the design context. Therefore, Deep Generative Models, which are proposed by the most recent developments of ANNs, have been examined by discussing the current methodologies used in recent design studies.

Finally, the project has been provided, which corresponds to the theoretical approach and methodology of the thesis and tests its premises. This project has been developed

for exploring the extensions of design cognition using physical architecture and 3-D Deep Generative models. The sensory data of the material architecture directly obtained from the physical environment was used in the project to experiment the relationship between the external world and cognitive processes. Datasets were produced by various experiments manipulating and transforming the real-world data according to architectural references and volumetric relationships based on the Extended Cognition Hypothesis and underlying principles of Computer Vision. These datasets were then processed with a Deep Generative Model to produce formal representations reflecting the extensions of design cognition. The new 3-D models produced by the Generative Model were embodied in different formal representations such as point clouds, mesh models and bounding boxes. These 3-D models creating a design vocabulary were then used for generating alternative combinatorial formations to extend design cognition.

The thesis therefore aimed at extending an approach of possible extensions of design cognition within the physical architecture by the following outcomes:

-It is appropriate to use mesh models and sensory data, which represent the 3-D nature of the system and provide the information of coordinates, in experiments where the cognitive information carried by the external world structures is used to naturalize information processing systems in design.

-In order for the cognitive information encoded in the design to be explicitly analyzed in information processing systems, the datasets to be used should be created by transforming the physical structure in accordance with the part-whole relationship and reference system, reflecting the design process.

-The use of Deep Generative Models is an effective method for analyzing the information about the cognitive processes underlying the design data and using it for alternative operations.

-Design vocabularies and combinatorial formations of the extensions of design cognition can be created to be used for further generative tasks. For this purpose, information processing systems are produced with the datasets created as a result of the transformation stages reflecting the design processes of the external world structures.

These outcomes of the thesis provide for a way of understanding the cognitive information embedded within material architecture and 3-D contexts. This approach could be used for alternative generative design tasks through Artificial Intelligence and Deep Generative Models.

This research experimented with the 3-D parts of a design context with its sensory data directly obtained from external world to generate a design vocabulary. The study therefore provided for an approach for processing real-world data to process the parts of a 3-D model with Deep Generative Models and to make spatial generations.

In a multi-disciplinary context bringing together developments and methodologies in neurosciences, cognitive and computer science, and computational design, the thesis explored a reconsideration of research on Extended Cognition both theoretically and practically by using material architecture with its sensory data to explore possible extensions of design cognition. The thesis hence conveyed an understanding of extended cognition in both its historical and current significance while experimenting with current strategies in computational design.

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