UNDERSTANDING TRANSFORMATIONS IN ARCHITECTURE
FROM POST-INDUSTRIAL CONDITION TO THE SECOND DIGITAL TURN

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ECE ALARA ALANKAYA

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submitted by **ECE ALARA ALANKAYA** in partial fulfillment of the requirements for the degree of **Master of Science in Architecture, Middle East Technical University** by,

Prof. Dr. Halil Kalıpçılar
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. F. Cânâ Bilsel
Head of the Department, **Architecture**

Prof. Dr. Celal Abdi Güzer
Supervisor, **Architecture, METU**

Examining Committee Members:

Assoc. Prof. Dr. M. Haluk Zelef
Architecture, METU

Prof. Dr. Celal Abdi Güzer
Architecture, METU

Prof. Dr. T. Nur Çağlar
Architecture, TOBB ETU

Prof. Dr. Zeynep Uludağ
Architecture, Gazi University

Assist. Prof. Dr. Esin Kömez Dağlioğlu
Architecture, METU

Date: 13.05.2022

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name Last name: Ece Alara Alankaya

Signature:

ABSTRACT

UNDERSTANDING TRANSFORMATIONS IN ARCHITECTURE FROM POST-INDUSTRIAL CONDITION TO THE SECOND DIGITAL TURN

Alankaya, Ece Alara
Master of Architecture, Architecture
Supervisor: Prof. Dr. Celal Abdi Güzer

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The influence between architecture and industry manifested itself in a series of new technical developments, styles, and trends in architectural practice in the 19th and 20th centuries. With the inclusion of the advanced machine of industry, 'computer' into this sphere of influence, the sequential mode of transformations furcated and dispersed into a reticulated structure and began to penetrate the fundamentals of architecture. Today, while the non-human intervention/involvement of advanced computation, robotics, big data, and artificial intelligence in daily life changes the social, cultural, and economic conditions, on the other, the transformations in architecture go beyond mere visual expression and technical advancements and affect thought, design, and fabrication process and organization of practice. Therefore, this thesis aims to understand the transformations in architecture from post-industrial condition to the Second Digital Turn by examining the emerging concepts and practices since the 1990s and the transformative relationship between industry and architecture from the beginning of the Industrial Revolution.

Keywords: Architecture-Industry Relationship, Digital Technologies, Computer-Aided Design and Fabrication, Architecture in Digital Age, Second Digital Turn

ÖZ

SANAYI SONRASI DURUMDAN İKİNCİ DİJİTAL EŞİĞE MİMARLIKTAKİ DÖNÜŞÜMLERİ ANLAMAK

Alankaya, Ece Alara
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Mimarlık ve endüstri arasındaki etkileşim, 19. ve 20. yüzyıllarda mimarlık pratiğinde bir dizi yeni teknik gelişme, stil ve eğilimde kendini gösterdi. Gelişmiş sanayi makinesi olan bilgisayarın bu etki alanına dahil olmasıyla, ardışık dönüşüm biçimi ağsı bir yapıya dönüştü, dağıldı ve mimarlığın temellerine nüfuz etmeye başladı. Günümüzde gelişmiş hesaplama, robotik, büyük veri ve yapay zekanın gündelik hayata insan dışı müdahalesi ve katılımı sosyal, kültürel ve ekonomik koşulları değiştirirken, diğer yandan mimaride ortaya çıkan yansımalar görsel ve teknik dönüşümlerin ötesine geçerek, pratiğin düşünce, tasarım ve fabrikasyon sürecini ve organizasyonunu etkilemektedir. Bu nedenle, bu tez, 1990'lardan bu yana ortaya çıkan kavramları ve pratikleri ve Sanayi Devrimi'nin başlangıcından itibaren endüstri ve mimarlık arasındaki dönüştürücü ilişkiyi inceleyerek, post-endüstriyel durumdan İkinci Dijital Eşiğe mimarlıktaki dönüşümleri anlamayı amaçlamaktadır.

Anahtar Kelimeler: Mimarlık-Endüstri İlişkisi, Dijital Teknolojiler, Bilgisayar Destekli Tasarım ve Fabrikasyon, Dijital Çağda Mimarlık, İkinci Dijital Eşik

To My Family

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ABBREVIATIONS	
AI	Artificial Intelligence
AR	Augmented Reality
BAS	Building Automation System
BIM	Building Information Modeling
BMS	Building Management System
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
CPS	Cyber-Physical System
H2H	Human to Human
H2M	Human to Machine
HBAS	Home Building Automation System
HVAC	Heating, Ventilation, and Air Conditioning
IoT	Internet of Things
IIoT	Industrial Internet of Things
IT	Information Technology
M2H	Machine to Human
M2M	Machine to Machine
VR	Virtual Reality

CHAPTER 1

INTRODUCTION

> All tools modify the gestures of their users, and in the design professions this feedback often leaves a visible trace: when these traces become consistent and pervasive across objects, technologies, cultures, people, and places, they coalesce into the style of an age and express the spirit of a time. The second digital style, the style of a data-affluent society and of a nouveau data-rich technology, is the style of the late 2010s.[1]

"In his "Talks in Google" speech about his book *The Second Digital Turn* in 2018, Mario Carpo marks a rise of a new direction in computer-aided design that drives transformations in architecture. Behind the new approach lies the interaction between architecture and one of the digital tools, namely artificial intelligence (machine learning and big data), which has advanced with recent developments in computational technologies. Using such computer intelligence as an ordinary tool in practice has revealed the potential to process billions of times more than a human's ability and an unfamiliar architectural language and expression hidden in the computer-aided architectural design and fabrication. In that regard, artificial intelligence manifests a disjointed, broken, fragmentary, discrete, and rough visual expression with its creative intervention into the nature of the way architects build and design.[2] In parallel with the transformation in architecture revealed in this speech by Carpo, the desire to understand the evolution of architecture through the previous industrial developments as well as the other transformations caused by digital technologies changing with current industrial development, Fourth Industrial Revolution constitutes the motivation for writing the thesis. This desire requires understanding the impact of previous industrial developments during the evolution

[1] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 55.
[2] Notes from, Talks at Google, "The Second Digital Turn | Mario Carpo | Talks at Google," *Youtube*, Uploaded 22 Mar. 2018, https://www.youtube.com/watch?v=UVerq5DSdKU Accessed 20 Apr. 2022

of architecture, in other words the transformative relationship between industry and architecture.

1.1 Problem Definition

The antecedent effects of industrial developments in architecture are mainly based on the revolution in the industry in the late 18th century. The system of production (constituted with a specific character in technology, a work organization, the relationship between labors and the labor-employer), consumption, and social structure, which preserved its form for centuries in feudalism, began to transform under the pressure of the two driving forces, the Industrial Revolution and the new economic model, capitalism. Besides the profit, which has become the ultimate objective, increasing the speed, flexibility, ease, and quality of production has triggered technological developments and thus brought new working environments, business organizations, and legal regulations. In addition, competition also developed the mode of production, a non-static, dynamic character that is led by the constant influence in between. In such a setting where sectors that can only be integrated into the new production system can exist, the changes caused by the industry emerged more or less simultaneously, became widespread, and left their place to new ones due to their dynamic character.[3]

It is accepted that there are four distinct revolutions within the many developments in this character in the industry. In the First Industrial Revolution, the emergence of steam engines, the use of mechanical tools, and factorization, the increase in fossil fuels took place. On the other hand, the Second Industrial Revolution differs from the previous one with the emergence of the assembly line, the use of electrical appliances and standardization, and the mass production of automobiles. The Third Industrial Revolution includes sharp changes with the emergence of the computer

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[3] İlker Belek, *Marxist Bakış Açısıyla BİLİMSEL TEKNOLOJİK DEVRİM VE "ENDÜSTRİYEL DEMOKRASİ"* (İstanbul: Sorun Yayınları, 1993), 15-17.

and the internet, the use of digital (computation) tools and automation, the linking of capital and labor to financial technologies, neo-capitalism, globalization, and the outbreak of global ecological crises.[4]

All these transformations revealed a problem of existence not only for businesses, institutions, and organizations but also for laborers and, of course, individuals of the society, who must have the knowledge and technological equipment to adapt to these periods. Along with the Industrial Revolution and the other essential machine, the clock, new "time consciousness" developed and mechanized both social life and man. Both the "work-time" and the "own-time" of the labor were also imprisoned in the capitalist system for a profit.[5] In addition to the domestic electronics and vehicles brought by the Second Industrial Revolution, the trends of the period, such as the American dream, the labor/effort of the industrial society was marginalized, and the role of consumer gained importance. During the Third Industrial Revolution, with the shift of production to the service sector and the financialization of the economy with digital technologies, qualified labor became precarious this time.

The concentration on economic actions with the Industrial Revolution and capitalism has also led to a tendency to see social/urban activities that shape the city like art, sports, and play as a waste of time. Such an environment has also caused every part of the city to become a negotiable commodity. In addition, while the city centers were enriched by world trade, the periphery of the cities became the settlement/slum area of the proletarian class that immigrated from the countryside, resulting in the initial divisions of the city. During the Second Industrial Revolution, the improvement in living conditions affected the urban development and architecture, rural life became a better option for the working population, and therefore areas such as suburban and satellite cities emerged. As a result of motorized and advanced transportation, which became widespread with the Third Industrial Revolution,

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[4] Raşit Gökçeli, *4. Endüstriyel Devrim ve Mimarlık* (İstanbul: Verita Yayınları, 2020), 9-13.
[5] Nigel Thrift, "The Making of a Capitalist Time Consciousness," in *The Sociology of Time*, ed. John Hassard (London: Palgrave Macmillan, 1990).

business areas, industry, recreation, and residential areas became distant and separated from each other. Urban centers and selected areas, which are at the center of globalization and financial opportunities, have been the basis for the development of architectural and urban precedents.[6]

It is debated whether the fourth revolution has taken place in the industry today. According to German engineer and economist Klaus Schwab and Turkish architect and city planner Raşit Gökçeli, the following developments prove that a new revolution is taking place with:

- the emergence of advanced computation in parallel with tools like artificial intelligence (AI), machine/deep learning (ML), quantum computers, and big data;
- usage of the robotic device and autonomous production that is developed by the advancements in nanotechnology, genetics, and biotechnology;
- omnipresence/ubiquity with mobile tech Cyber-Physical Systems (CPS) and the Internet of Things (IoT);
- occurrence of mixed reality (MR) environments derived from virtual reality (VR), augmented reality (AR), and metaverse concepts;
- advancements in sustainable agriculture (permaculture, hydroponic), waste management, minimization of energy consumption;
- transformation in the economy from production of goods/provision of services to new virtual forms that include blockchain, cryptocurrency and NFT.[7,8]

While Industrial Revolutions were changing society and the built environment, architecture, like all other fields, tried to embrace and adapt to technological innovations in the work. While the reflections of the technical innovations (new

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[6] Raşit Gökçeli, *4. Endüstriyel Devrim ve Mimarlık* (İstanbul: Verita Yayınları, 2020), 13.
[7] Klaus Schwab, *The Fourth Industrial Revolution* (Geneva, Switzerland: World Economic Forum 2016), 7.
[8] Raşit Gökçeli, *4. Endüstriyel Devrim ve Mimarlık* (İstanbul: Verita Yayınları, 2020), 9-13.

materials and tools) that emerged with industrial developments in architecture differ, the interpretations of the periods also differ in the same way. Architectural critic Reyner Banham defined the period from the late 19th century to the 1930s as the “First Machine Age”, the age of “power from the mains and the reduction of machines to human scale” while explaining the influences of technology and its impacts on functionalism, machine aesthetic and language of modern architecture.[9] On the other hand, French architect Le Corbusier also said unlike architects, cars, planes and ship makers knew how to deal with the advanced technology of the mass production and assembly line.[10] Although experiments were done with Taylorism and Fordism by the architects of the period,[11] it was not developed due to the non-profitable character of the dwelling units in terms of its spatial and technical attributes. The mass-production of the identical and standardization were not the right technology to be integrated into the architecture.

Banham defined the period he was living as the "Second Machine Age," the age of "domestic electronics and synthetic chemistry," as he had explained in the second edition of his book *Theory and Design in the First Machine Age* in 1967. As we enter the Second Machine Age, the influence of the spread of communication and media technologies such as print media, television, cinema, and last but not least, computer to architectural practice was unprecedented. This new kind of communication shifted the understanding of local time to world time while emerging new terms like immediacy, omnipresence, and instancy that affected the perception of space-time. Such an unusual flow of printed information and motion emerged a mass consumption of images and a new kind of material culture. In such an environment, Martin Pawley, in his book *Theory and Design in Second Machine Age*, pointed out a reduction of architecture to the imagery and a tendency toward visually-oriented

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[9] Reyner Banham, *Theory and Design in the First Machine Age, 2nd Ed.* (New York, Washington: Praeger Publishing, 1967), 9-11.
[10] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 2
[11] Ibid.

practice rather than a theoretically-oriented one. According to Pawley, the new machine age began with the transition from modern architecture, a product of logic and reason, to the post-modern architecture of visuals, styles, and trends. Many additional architectural elements to buildings were a consequence of aesthetic concerns rather than a technological necessity.[12] The relationship between architecture and industry until the invention of the computer-machine did not meet the architectural language and form expectations.

Starting from the early 1990s, the inclusion of computer and digital tools (CAD, CAM) in the architectural design process was the prominent turn of the Third Industrial Revolution. Early applications of digitalization and "calculus, the mathematics of continuity" in architecture emerged itself "with the style of the blob, also known as the style of the spline or digital streamlining" that demonstrates smooth, curving lines and surfaces, which is later called parametricism.[13] At the same time, "NURB modelers" also stimulated the emergence of "folding" style that was inspired by the "rhizome, multiplicities, assemblage, smooth space, line of flight, deterritorialization, becoming intense, and abstract machine" notions from the Deleuze and Guattari's *A Thousand Plateaus*.[14] For this reason, German architect and architectural theorist Patrik Schumacher defended the folding style by emphasizing its importance in terms of creating new spatialities and formations.

On the other hand, digitalization has broad consequences for new information, operation, and organization systems. As one of the theorists of Post-industrial society, The French philosopher Jean-François Lyotard observed the alteration of the way of transmitting and acquiring information due to the process of "computerization" and changing status and legitimacy of the knowledge and remarked on the emergence of "complexities and divisions" in many disciplines.[15]

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[12] Martin Pawley, *Theory and Design in the Second Machine Age* (Oxford: Blackwell, 1990).
[13] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 4
[14] Patrik Schumacher, *DIGITAL - The 'Digital' in Architecture and Design* London 2019
Published in: AA Files No.76, Architectural Association, 3
[15] Jean-François Lyotard, *The Postmodern Condition: A Report on Knowledge*, 1979.

The architectural practice which has already been an intricate process with the mega-scale buildings, became a more organizational process with the CAD. In that sense, new disciplines like project management and services like design consultants emerged to bridge the gap that widened with the complexity of buildings.

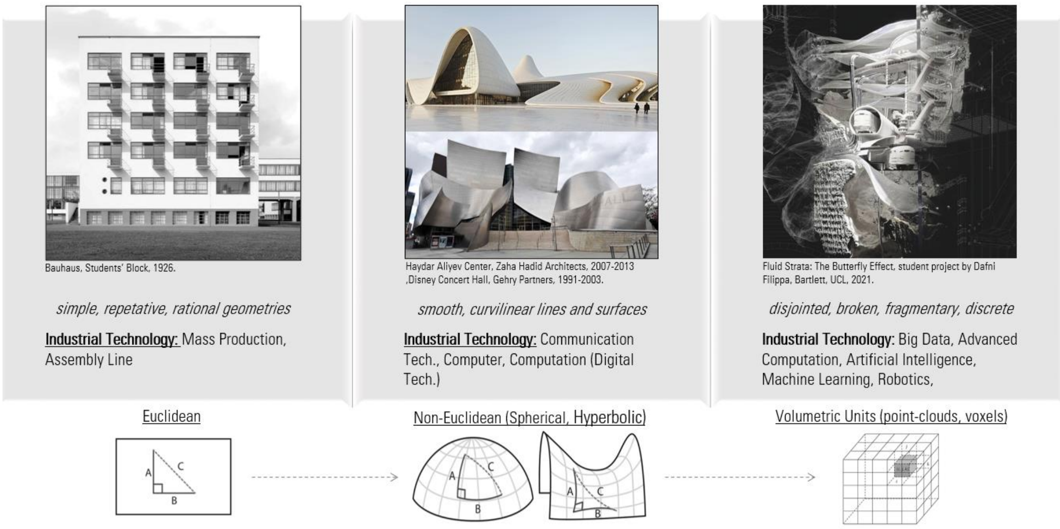

Figure 1.1. The Transformations in Comparison. Retrieved from Personal Collection, 2022.

> Marx's critique of the Industrial Revolution, meant the industrial separation of the hands of the makers from the tools of production, may just as well be applied today to the ongoing postindustrial separation of the minds of the thinkers from the tools of computation.[16]

Since the 2010s, an unprecedented range of data, 'big data' that was rare and expensive before, ubiquitous and cheap now, has become one of the apparatuses that signaling another turn to the Second Digital Turn. Engagement of Data-driven AI/ML and computation has created a language of a "messy discreteness" with "point-clouds" and "disjointed and fragmentary states" with "volumetric units" and voxels in architectural design and manufacturing. The electronic brain can now do billions of notations and calculations that the human mind cannot do. The alteration in the way of thinking from the human mind to computation results in an unknown,

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[16] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 81.

unfamiliar expression related to the machine's intelligence.[17] On the other hand, there is a vast range of digital tools, which includes IoT, robotics, biotechnology, MR that is embraced with the spatial, ecological, economic or aesthetical attitude that is revealing new possibilities of the relation between architecture and industrial innovations.

In addition to its own dynamics, architecture has been affected by the transformations in other fields and their reflections, and on the other hand, it becomes their representation. On top of these factors, technological transformations and thus new possibilities, limits, and additions they bring comes fore. For this reason, it is essential to try to understand the transformations in architecture together with these transformations instead of considering them as preferences arising from their own field.

1.2 Aim and Scope

This thesis aims to understand transformations in architecture from the Post-Industrial condition to the Second Digital Turn and reveal the emergence of the current interaction between developments in digital tools, fabrication techniques, and transformations in architectural design.

There is an expedited change between technology and the built environment after the post-industrial process, which is manifested not only in the technical and constructional status of architecture but also in the organizational aspects of the practice that has had multidimensional consequences. Therefore, this thesis emphasizes and intends to understand the consequences of the improvements and technological developments that materialized in architectural language and its expression and the new organizational dimension and relation systems due to digital culture's new interactive, collaborative, participatory environments.

[17] Ibid.

With the motivation to understand the consequences of the Fourth Industrial Revolution and its reflections on contemporary architecture, this thesis mainly focuses on the period from the 1990s, the inclusion of digital and computation technologies, to today. However, the scope of the contents expands to the historical background of the industry in order to understand the revolutions in industry and their impacts on architecture.

1.3 Methodology and Structure

Understanding the transformative relationship between architecture and industry reflected in contemporary architecture's design, construction, and thought process required an initial examination of industrial developments and their transformative effects on architectural practice. The second part of this thesis represents background research of questions regarding the series of transformations from mechanization to computerization that has had far-reaching consequences for society, culture, economy, urban, and architecture. Therefore, beginning with industry definition, the chapter "Transformative Relations in between Architecture and Industry" tries to understand the context of industrial developments and the transformative influence of industrialization upon architectural theory and practice. In this section, Reyner Banham's *Theory and Design in the First Machine Age* and Martin Pawley's *Theory and Design in the Second Machine Age* offer an architectural perspective parallel to industrial developments in this thesis as a different assessment of the period.

Before moving into transformations in architecture, in the third chapter, the current transformations in the industry are examined through many different perspectives, such as the post-industrial age, information age, network age, and the transformative influence of the industry along with the constant scientific and technological changes is investigated through social and economic consequences. This transformation, which started with computerization, is also discussed through newly emerging definitions like Third Machine Age and the Fourth Industrial Revolution with new additions to existing network systems, virtual spaces, and new media.

In the fourth chapter, to understand the current condition of the relationship between architecture and industry, the applications of recent technologies and industrial production techniques in architecture are investigated through the works of architects and researchers. The transformation of the architectural language, space, material, construction, and hardware is analyzed, and distinctive reflections of industrial transformations on contemporary architecture are highlighted. Throughout the process, both theories and practices of Greg Lynn, Antonio Picon, Patrik Schumacher, Mario Carpo, Branko Kolarevic, and several other architects and researchers are studied as prominent mentors of digital architecture. The conclusion chapter represents the outputs of the transition from the post-industrial condition to the second digital turn and the impacts of previous Industrial Revolutions on architectural practice, society, and the city.

CHAPTER 2

TRANSFORMATIVE RELATION IN BETWEEN INDUSTRY AND ARCHITECTURE

The shifts between societies were intermittent over the millennia, from primitive man to the Industrial Revolution. With the technical revolution in the 19th century, society entered into a cycle in which it started to change constantly within a short time compared to past conditions. The frequency of these transformations has increased as it gets closer to the current period and has created a pattern that the time*line* of alterations has begun to ramify, intersect and reticulate with further connections with diverse disciplines.

Architecture, on the other hand, has been related to production since the first human being turned into a *homo faber*.[18] The effect of the transformative Industrial Revolution and the subsequent developments caused changes not only in the technique of architecture but also in its language, expression, and even in its motivation. The reflections of the relationship between industry and architecture, two entities that affect and transform each other in architecture, can also be perceived by following these transformations. In this chapter, a brief description of the Industrial Revolution and the relationship between industry and architecture is provided in order to understand the contemporary relation and its architecture.

2.1 The Context of Industrial Developments

From Industrial Revolution to the current industrial condition, industrial developments have had economic, social, political, and cultural impacts that also had

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[18] Defines the humankind as a maker that uses tools. See: "Definition of Homo Faber". *Oxford University Press*, https://www.lexico.com/definition/homo_faber Accessed 20 Jan 2022

reflections on the built environment. These industrial developments encompass a process that extends from the initial influences of reformation and enlightenment movements that altered the mode of reasoning in Europe during the Industrial Revolution to the current multi-dimensional influence of digital environments and computer intelligence. The periods that emerge from the observations on the relationship between technological developments (Industrial Revolutions) and social transformations are referred to with different periodic terms by researchers and theorists. Regarding the economic growth policies of governments, numerically indexed concepts such as "Industry 3.0" and "Industry 4.0" are used to express an update and improvement or an aim in the industry. On the other hand, the "Machine Age" focuses on the impacts of transforming machines during these industrial developments on society and architectural theory and design. With an intention to comprehend the context of industrial developments, this chapter initially starts with understanding the Industrial Revolution and its direct social and environmental-/urban impacts. Secondly, the research expands to understand the effects of the later revolutionary industrial periods and distinct machines of these periods. Moreover, it ends with brief research of what point today's industry stands according to these studies, which will be discussed more broadly in the next chapter of the thesis.

2.1.1 Definition of Industry

As the term 'industry' is etymologically investigated, early Latin words and their meaning, industria "diligence" and industrius "active, diligent,"[19] come forth, which was used to indicate a cleverness and skill in the pre-industrial period. In the modern sense, the term gradually came into meaning as manufacturing goods in factories and

[19] "Definition of Industry". *Online Etymology Dictionary,* www.etymonline.com/word/industry. Accessed 21 May 2021

an economic activity commonly related to raw material processing.[20] In the end, congruently, both these meanings of 'industry' describe a production characteristic of these periods.

Table 2.1. Definitions of Industry.

Pre-Industrial Age	***Industrial Age***	***Post-Industrial Age***
. Cleverness . Skill	. Machinery manufacturing . Processing of raw materials . Economic activity	. Providing services . Producing intangible value

The meaning machinery manufacturing of the term industry came fore with the Industrial Revolution, which primarily occurred in Britain between 1740 and 1780. The revolution was a unique phenomenon in humankind's history, which had vast repercussions throughout the society, economy, and landscape. Both urban and rural settlements of the modern-day are the result of this industrialization process.[21] In addition, the transformation of the term industry also indicates a difference between the pre-industrial and industrialized stage. It is understood that on one side, the pre-industrial society was highly concerned with the skill and craft; on the other side, the industrial society was to the manufacturing and machine-made.

The shift from skill to machinery within these definitions marks a transformation in the dominant mode of production and making throughout the period. Technology, economy, capital, population (which is related to the quantitative side of demands and labor), increasing trade, and growth of markets are factors that affect and shift

[20] "Definition of Industry". *Oxford University Press,* www.lexico.com/en/definition/industry Accessed 21 May 2021

[21] Neil Cossons, *The "BP" Book of Industrial Archaeology* (London: David & Charles, 1978)

the production techniques and eventually the industry. During the Industrial Revolution, the radical changes in production technologies in a relatively short time due to these factors were ultimately revolutionary. The new structure of society and industry caused chained reactions within the economy (from backward economy to modern economy to global economy) and had many consequences in culture besides the transition in production from hand-tool to machine-too.[22]

The process of change from machine to automatic and digital can only express the industrial advancements reduced to a single layer. However, as mentioned above, this change process has affected many areas at each rupture, simultaneously generating new layers of influence. At this point, as culture, politics, economics, and even individuals of society transformed into an industry, it also provides further grounds for discussions through many new layers and new fields. Such fields can be illustrated as 'culture industry,' 'consciousness industry,' 'tourism industry, and more. Consequently, as a constantly transforming concept, industry articulates and changes society and its other dimensions.

2.1.2 Industrial Revolution | Mechanic Production

The Industrial Revolution is the phenomenon that emerged with the transformation of the production process, which was carried out with human and animal power in the 18th and 19th centuries, with machines working with steam and water power, and the transformation of production into mass production.[23] The revolution in the industry was also affected by the developments that took place in Europe in the 16th and 17th centuries. The pre-industrial period was under the influence of reformation and enlightenment movements. Within these periods, the "Reformation decreased the power of the Pope and led to national unifications, and enlightenment freed

[22] Neil Cossons, *The "BP" Book of Industrial Archaeology* (London: David & Charles, 1978)
[23] A Mahfi Eğilmez, *Dünya Ekonomisi : Tarihsel Süreç İçinde* (İstanbul, Remzi Kitabevi, 2018), 97.

human reason from scholastic framework."[24] This process, which brought science and reason to the fore, later triggered technological and scientific developments and inventions.

In addition, simultaneous conversion to fossil fuels (coal reserves) and agriculture fed the capitalist developments in Europe and was mutually beneficial to the Industrial Revolution.[25] During and even before the revolution, these capitalist developments led to rapid population growth and the demand for ready-made labor. In the same period, while the precious metals coming to Europe from the colonies affected the welfare level, it also increased the demand for consumer goods. All these developments paved the way for new investments and, thus, laid the foundations of the Industrial Revolution. Because of these reasons, England had more potential for the revolution than other countries. For instance, England was rich with the necessary coal and iron raw materials due to a large number of colonies and cost-efficient transportation (naval) of raw materials.[26]

James Watt led to the revolution of industry in the 1760s by advancing the steam engine, which Thomas Newcomen found and developed in 1712, into a less costly, efficient tool. The economic structure of the period from the feudal era to the Industrial Revolution was based on agriculture and animal husbandry, workshop industry, and services. Some of the income that did not consume was saved and invested in production to be evaluated for sale in foreign trade and fairs. From such an economic structure to factories where people work collectively to mass-produce was revolutionary. In the end, after the revolution, the production becomes both increased and got cheaper with a steam engine and coal adjustments.[27]

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[24] Davut Ateş, "Industrial Revolution: Impetus Behind the Globalization Process." *Yönetim ve Ekonomi* vol. 15, no. 2, (2008): 31-48 Retrieved from DergiPark. https://dergipark.org.tr/tr/download/article-file/145992
[25] David Harvey, *Seventeen Contradictions and the End of Capitalism* (New York, Oxford University Press, 2015), 3.
[26] A Mahfi Eğilmez, *Dünya Ekonomisi : Tarihsel Süreç İçinde* (İstanbul, Remzi Kitabevi, 2018), 97-98.
[27] Ibid., 96.

2.1.2.1 Impacts of Industrial Revolution

The history of makers came into light while experiencing nature and material and crafting tools out of necessity. Tools improved over time from the most primitive status to machines;[28] hence, each epoch had its technics, tools, or machines to produce, to bring forth into existence. With a mere statement, French philosopher Bernard Stiegler conveys what is meant to be said, "the human invents himself in the technical by inventing the tool."[29] Thus, every technological invention (tools, devices, knowledge…) somehow reflects its impact on society and its other dimensions, including the built environment. According to Stiegler, the harmony between humans and technics has deteriorated since the Industrial Revolution's advent. He asserts that the period since then was such a radical change that humankind had not sensed this technical dimension for thousands and millions of years. Stiegler explains this situation, which is considered to be the first time in human history, through the phenomenon of "Technologie de rupture."[30] In this phenomenon, also known as *a disruptive technology*, it is accepted that technological changes have a definite effect on economic growth and industries' development. However, not every change affects environmental conditions. In this context, whether technological change is *disruptive* or *enhancing* becomes significant.[31] According to Stiegler, the technological changes in society before the Industrial Revolution were the impacts that improved the production process, that is, without changing the environmental conditions. The new technology back then was a new

[28] Distinguishing aspects of tools and machines: tools are instruments worked by hand, such as a stone chip or a hammer, or a saw, while machines are an assemblage of parts acting together for a common purpose. See: Bruce Mazlish, *The Fourth Discontinuity: The Co-evolution of Humans and Machines* (Yale UP, 1993)
[29] Bernard Stiegler, *Technics and Time: The fault of Epimetheus* (Stanford UP, 1998), 141.
[30] The term “technological rupture” coined by French historian Bertrand Gille. Throughout the history such technological ruptures occurred over time. One can understand the concept by relating these ruptures to the historic eras (pre-historic era, classical era). Previously, each rupture was very far apart from each other. After Industrial Revolution the gap between them narrowed in an unusual manner.
[31] Michael L. Tushman and Philip Anderson, “Technological Discontinuities and Organizational Environments,” *Administrative Science Quarterly*, Vol. 31, No. 3, (Sept. 1986): 436-465, doi: 10.2307/2392832. Accessed 21 Mar. 2022.

addition to the production process. However, it does not mean that disruptive technologies have not occurred before the revolution. Although it caused the collapse of authority in communities and industries, harmony was re-established until the next disruptive technology. Stiegler emphasizes that society is experiencing too many disruptive technologies in such a short time after the Industrial Revolution. The distance between these changes is diminishing and disappearing to the extent that cannot be followed and adapted. The consequences of these rapid technical transformations can be observed as an unstable state of systems (social, cultural, economic, and political) that demands constant changes and divisions later on.[32]

On the other hand, technology came to the fore as a new field of business with the Industrial Revolution. Other countries, institutions, and investors, who learned from England's economic growth and development process, behaved technology and science as a new profit field. Technological changes fed by capital in the capitalist system begin to take their driving force from these investors. Harvey illustrates this interaction with the development and *diversification* that occurs as manufacturers adapt steam engines and other unregistered technologies to different industries for profit.[33] In the end, highly supported technological change gradually accelerated throughout the revolution.

2.1.2.1.1 The Transformation of Society and the Mechanized Man

In this section, the transformation of society is discussed through the effects of the changing work, time and space phenomena with the Industrial Revolution. The first of this process begins with a change in the definition of work. Craftsmanship production, which continued in workshops until this period, started to leave its place in factories and mechanical production. This transformation caused the loss of some

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[32] Almafarag, “Man & Technics: Bernard Stiegler,” *Youtube*, Uploaded 16 Feb 2011, https://www.youtube.com/watch?v=ymtnUDAOEWc Accessed 13 Mar. 2021

[33] David Harvey, *Seventeen Contradictions and the End of Capitalism* (New York, Oxford University Press, 2015), 94.

manual skills and abilities, and the standard methods at that time, such as giving work to houses and families through small workshops, gradually began to disappear. These workshops, which dominated production before the industrial period, were able to reach a certain extent of mass production by employing a small number of workers in the workshop.[34] Additionally, every individual development during the Industrial Revolution accelerated technical progress and required specialization in the use of machines and division of labor in the production process. In this process, the existence of skilled craftsmen based on individual production has come to the brink of extinction. Craftsmen's skills are also obsolete when the machine is put into service. Any worker in the factory, regardless of ability, is reduced to the status of an ordinary worker, to a subsistence wage.[35]

On the other hand, with the proliferation of factories, the acceleration of manufacturing, and the rise in trade, the Industrial Revolution reached such a point that intense competition between machinery-made goods and firms themselves started and intensified. Due to the economic competition, the gap between the two classes, the middle class (bourgeois) who owned the means of production and the working class (proletariat[36]) who only possessed their labor power, widened. Under the newly emerged unregulated system, as the profits of the company owners increased, the working class struggled more with low wages, poor working conditions, and unhealthy living standards with high rents. In addition to the ill working environment and standards, the fact that child workers were taken from orphanages to work stands out as another detail that shows the harsh conditions of that period. As a witness to the evolution of industrial capitalism, Engels analyzed the social impacts of the industrialization and its economic and political consequences:

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[34] A Mahfi Eğilmez, *Dünya Ekonomisi: Tarihsel Süreç İçinde* (İstanbul, Remzi Kitabevi, 2018), 98-99.

[35] Hüseyin Özalp, Leyla Firuze Arda Özalp, "Teknik Değişim ve Emek" *Yeni Eko-Tek Dünya Teknolojinin Son Sürümü,* 14-16, Retrieved from ResearchGate, Accessed 21 Mar. 2022.

[36] Karl Marx used the term *proletariat* to describe the entire working class in an economic system he called the industrial capitalism who can only earn money by selling their labor.

> The proletarian is helpless; left to himself, he cannot live a single day. The bourgeoisie has gained a monopoly of all means of existence in the broadest sense of the word.…The proletarian is, therefore, in law and in fact, the slave of the bourgeoisie, which can decree his life or death. It offers him the means of living, but only for an "equivalent", for his work.[37]

To defend labor rights, uprisings by the working class began soon after and passed through several phases with few triumphs. One of the reasons that workers took action was the long working hours. Nevertheless, according to British academic and geographer Nigel Thrift, time was already a lost cause even though the workers would gain a few leisure hours. The new consciousness of *time* was penetrating the daily life of industrial man, but the workers were only fighting for the work-time modifications. In this sense, while following the traces of this new time perception change in its article *The Making of a Capitalist Time Consciousness*, Thrift also examines which factors affect this consciousness that society has unwittingly adapted.

First and foremost, the pre-industrial social life was away from the "system of instrumental action" brought about by working with machinery. Until the 15th century, the "daily" life of society was set upon the sun movement and sundials that were often located on church walls, the "week" was uncommon, and the cycle of the "year" was dependent on the agricultural almanac, or religious calendar.[38] Works were predominantly task-oriented. The payment was given according to that orientation. In the end, "the organisation of the day, week and year in rural areas in mediaeval times was therefore rhythmic rather than measured."[39] For this reason, the consciousness of the future was not formed in the society; it would neither be measured, nor calculated as a probability, nor imagined. In the 100 years before the Industrial Revolution, clocks were used partly in houses, mostly in public spaces,

[37] Friedrich Engels, *The Condition of The Working Class in England* (Harmondsworth, Middlesex, England, New York, N.Y., USA, Penguin Books, 1987), 107.
[38] Nigel Thrift, “The Making of a Capitalist Time Consciousness,” in *The Sociology of Time*, ed. John Hassard (London: Palgrave Macmillan, 1990).
[39] Ibid., 107.

church walls, and marketplaces. At that time, household clocks were not widespread enough to integrate into the daily life of society.

On the other hand, public clocks were used in general, however, to announce only certain times of the day. As the time came near the Industrial Revolution, pocket watches became a significant development in society and the watchmaking industry. However, its use appealed to a particular class and people due to its cost until the revolutionary period.

> The clock, not the steam-engine, is the key-machine of the modern industrial age. For every phase of its development the clock is both the outstanding fact and the typical symbol of the machine: even today no other machine is so ubiquitous.[40]

The modern time consciousness, which gradually developed with the emergence and infrequent use of clocks, became a social phenomenon with the onset of the Industrial Revolution. In the case of the workers, participating in production in factories required adapting to the machine's rhythm. Since the product belonged primarily to the capitalist, not to the worker who produced it, it became necessary to be disciplined, punctual, and standard. Moreover, since the future-time could now be imagined, calculated, and invested, the capitalist system fueled by these profits calculations was required to run like clockwork. At such a point, the *mechanized man* emerged in industrial societies.[41] Works were now mostly time-oriented (weekly wage, monthly wage) rather than task-oriented, demonstrating the transformation of employers' aim from task to worker's time. Time has ceased to be a transcendent element of human experience and has become an *objective force*, embodied, measured, and calculated with activities such as work times, leisure times, visiting times, meal times, dressing-times, family visiting days, and holidays. This division, at some point, brought about the separation of *own time* and other times;

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[40] Lewis Mumford, *Technics and Civilization* (London: Lowe and Brydone Ltd., 1955). 14.
[41] Nihan Gider, “Zaman Makinesi (Doğal Zamandan Saat Zamanına Geçiş Mekanik Zaman)” (MSc Thesis, 2004), https://www.proquest.com/thesiss-theses/zaman-makinesi-doğal-zamandan-saat-zamanına-geçiş/docview/2563805919/se-2?accountid=13014, 14-16.

thus, the *day* has become alienated from the individual of modern society.[42] The capitalist system, which transformed working into a rigid system, also arranged the leisure time as another domain of profit. *Leisure-time*, which was supposedly the individual's own time, has become the time not to participate in entertainment, activities, and experiences but to consume.

2.1.2.1.2 The Transformation of Cities and the Urbanization

Before the Industrial Revolution, cities such as Amsterdam and London created their bourgeois class by expanding rapidly with international trade and colonization and were already the focal points of economic development. While these trading cities seemed to herald the coming of the Industrial Revolution, the effects of the revolution and power-controlled capitalism on the built environment were highly unequaled. The initial reflections of the process were not seen in metropolitan cities such as London but small towns close to raw materials like iron and coal. Later, with the mechanization of weaving in the textile industry, the rest of the production processes started to become mechanized. With the advent of the steam engine, the importance of water significantly increased, and the *mills* quickly covered the waterfronts of the towns. In order to accelerate the efficiency of the industry, channels were built, and the mills were lined up around these channels and rivers. Almost every building was built without an architect in industrial towns like Colebrook and Lowell, with a few exceptions. It is this civic architecture and engineering that gives shape to these cities.[43]

The steam engine, which increased the workforce's productivity in many areas and accelerated production, had to be concentrated in accessible, central points due to their large and heavy forms. Therefore, towns became at the forefront in terms of

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[42] Nigel Thrift, "The Making of a Capitalist Time Consciousness," in *The Sociology of Time*, ed. John Hassard (London: Palgrave Macmillan, 1990), 112.
[43] Kathleen James-Chakraborty, "Chapter 17: The Industrial Revolution," in *Architecture since 1400* (Minneapolis: University of Minnesota Press, 2013), 254–72.

both the flow of trade (market) and the labor force (workforce). The increasing number of factories and the resulting labor force proceeded to another phase by initiating migration from the countryside to towns. Lewis Mumford defined this new condition of aggregation in towns on two foundations.

> **The political base** of this new type of urban aggregation rested on three main pillars: the abolition of guilds and the creation of a state of permanent insecurity for the working classes: the establishment of the competitive open market for labor and for the sale of goods: the maintenance of foreign dependencies as source of raw materials, necessary to new industries, and as a ready market to absorb the surplus of mechanized industry. **Its economic foundations** were the exploitation of the coal mine, the vastly increased production of iron, and the use of a steady, reliable - if highly inefficient - source of mechanical power: the steam engine.[44]

Table 2.2. Technical Aspects of Pre-Industrial Age vs Industrial Age.

	Pre-Industrial Age	***Industrial Age***
Technical Element	Hand-Tool	Machine-Tool
Production Technique	Craftsmanship	Mechanic
Producer Type	Craft Producer	Mass Producer
Worker Class	Skilled Worker	Manual Worker
Production Location	Atelier	Factory
Common Resource	Local material	Raw material
Economic System	Agricultural and Livestock	Industrial
Technological Transformation Pattern	Intermittent	Sequential

[44] Lewis Mumford, *The Culture of Cities* (New York, Harcourt, Brace and Company, 1938), 145.

The outcome of these foundations occurred in the factory centers when factories were built near the energy sources and received a large labor force from the countryside. For example, Manchester, known for its cotton industry in England, expanded from a "modest town of 25,000 in 1772 to a metropolis of 367,232 by 1851". Similarly, other towns, including Leeds, Birmingham, and Sheffield (textiles and metalwork), "grew by 40 percent between 1821 and 1831 alone". On the other hand, this new condition uncovered transportation issues as well. Inventors were influenced to find an efficient solution to transfer goods and raw materials. At that time, improving transportation meant improving roads and a spate of canal building; however, these solutions were insufficient and did not contribute much to brand new manufacturing. Within this accelerated environment, in 1825, trains with locomotives were invented in England and began to be used for the transport of goods, people, and even information, thereby becoming a revolutionized link between towns.[45] Consequently, beyond the change in the mode of production, the impacts of raw materials, energy sources (water, steam...), and investors were reflected in the formation of cities, human density, and transportation.

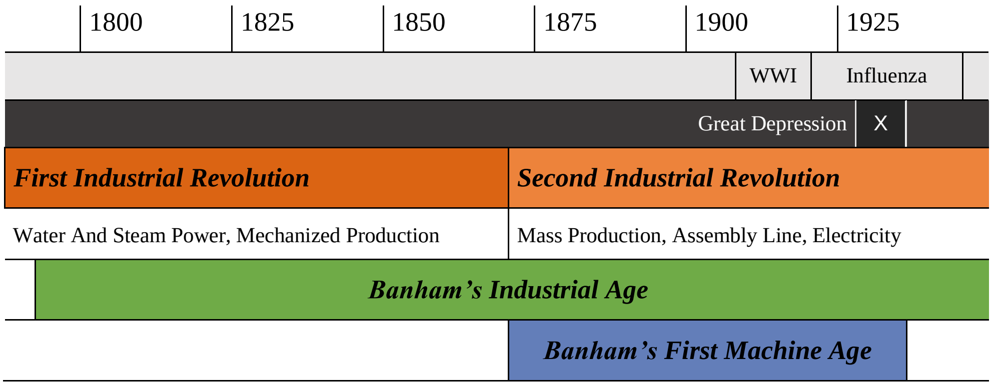
2.1.3 Second Industrial Revolution | Mass Production

After the mechanization of the production, the industry moved one more step with Second Industrial Revolution, to mass production with an assembly line initially used for the meatpacking industry around the 1870s. In his book Theory and Design in First Machine Age, the era is also marked as the First Machine Age by Reyner Banham. Though he does not state an exact date for what he called the "First Machine Age," it can be understood as the time from the last decades of the 19th century to the 1930s, as also observed and explained by Martin Pawley in his continuation book *Theory and Design in Second Machine Age*. The Industrial Revolution and the early period of the industrial age are defined as a period of large-scale machines that

[45] Peter N. Stearns, *The Industrial Revolution in World History, 4th ed.* (Westview P, 2013), 38-39.

significantly impacted production and social life. In that sense, Banham defines the First Machine Age as another revolutionary period until the Second Machine Age in which the influence of small machines like "shavers, clippers, and hair-dryers; radio, telephone, gramophone, tape recorder, and television; mixers, grinders, automatic cookers, washing machines, refrigerators, vacuum cleaners, polishers"[46] came to the fore as the new sense of living that society was going through.

Table 2.3. First Machine and Industrial Age in the Timeline of the Period.



S. Giedion, in his "Mechanization Takes Command," traces the evolution of the 'assembly line' under long chapters, from non-mechanical to the most advanced applications. He summarizes the purpose of the assembly line with his words, "The growth of the assembly line with its labor-saving and production-raising measures is closely bound up with the wish for mass-production."[47] Henry Ford used and improved this attitude for the mass production of an entire automobile in 1913. Later, this standardized, mass-produced, and mass-consumed new way of manufacturing was called Fordism. The impacts of Fordism on the production process, labor, space, state, and even ideology were pointed out by D. Harvey with a table summarizing everything. According to it, the transition in terms of the labor and the process was from "multiple tasks to the single-task performance by worker" (a division of labor);

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[46] Reyner Banham, *Theory and Design in the First Machine Age, 2nd Ed.* (New York, Washington: Praeger Publishing, 1967), 9-11.
[47] Siegfried Giedion, *Mechanization Takes Command, a Contribution to Anonymous History, Third Printing* (New York: Oxford University Press, 1970).

from "on the job learning to no learning experience; from small batch production to uniform, standardized mass production"; and more importantly from "demand-driven production without stocks to resource-driven production including large buffer stocks and inventory."[48] As the technology strengthened its presence within this system, nature became the resource for accelerated everyday business with powerful machines.

In the late period of the era, the resource-oriented mass production caused overproduction and brand-new stocks system within this transition. In *the Question Concerning Technology*, M. Heidegger examined the modern technology to its essence (which he defines as "enframing (Gestell)") and wrote about the new status of the resource, standing-reserve (bestand): "Everywhere everything is ordered to stand by, to be immediately at hand, indeed to stand there just so that it may be on call for a further ordering." For further discussions, Heidegger adds, "If the man is challenged, ordered, to do this, then does not man himself belong to even more originally than nature within the standing-reserve?" As mentioned at the beginning of the chapter, the human finds and relates itself to nature and the world in the technical. However, herewith the modern technologies, nature, and human life were objectified and turned into exploitable, consumable resources for energy for everyday business.[49]

In the meantime, the science that had come to the fore with curiosity and philosophy in the Enlightenment Movement reached its highest levels in the industrial age, with the capital which served as the driving force. Accelerated research and development activities[50] in corporate-supported scientific laboratories and factories also influenced technological developments and resulted in science-based technologies.

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48 David Harvey, *The Condition of Postmodernity: An Enquiry into the Origins of Cultural Change* (Blackwell Publishers, 1992), 177.

49 Heidegger, Martin, and William Lovitt. *The Question Concerning Technology, and Other Essays* (New York: Harper & Row, 1977), 3-35

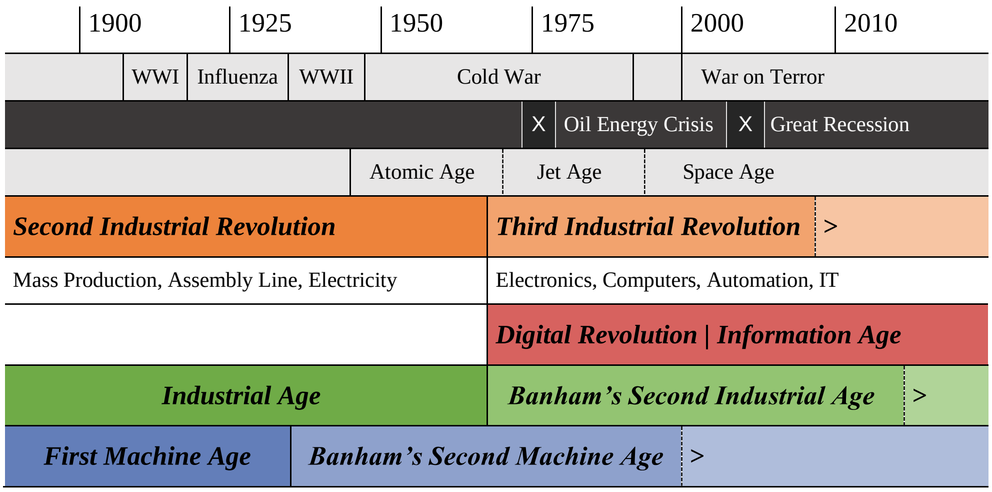
50 In these years, “Research and Development” (R & D) symbolized the joining of science, technology and economics. See: Daniel Bell, “The Axial Age of Technology” in *The Coming of Post-Industrial Society: A Venture in Social Forecasting* (New York: Basic Books, 1999).

Such developments included x-ray, radio, gasoline-powered autos, airplanes, polymers, and electronics in the 19th century, which were the forerunners of more ambitious projects like the NASA space program, wireless network, and computers.[51]

2.1.4 Third Industrial Revolution | Automatic Production

Starting from the 1930s _when R. Banham ended the First Machine Age_ Martin Pawley continues to analyze the new condition of the relation between industry and architecture. He discusses it under the "Second Machine Age." The same period was also named the Atomic, Jet, and Space Age, started around the end of WWII in the 1940s and continued in parallel with the Cold War. Later, with the developing industry, the Third Industrial Revolution began around the 1970s, which is also included in the period of Pawley's Second Machine Age. After that, the influence of the invention of the computer, the Digital Revolution, and the Information Age could be traced through the later periods of the Second Machine Age.

Table 2.4. Second Machine and Industrial Age in the Timeline of the Period.



[51] Peter N. Stearns, *The Industrial Revolution in World History, 4th ed.* (Westview P, 2013), 75.

As for the Second Machine Age, R. Banham was the first to point out the transition to the Second Machine Age around the 1930s. Banham distinguishes the period with the developments in "domestic electronics and synthetic chemistry."[52] The 1930s are also crucial in terms of being the post-war period. What makes this period as revolutionary as the Industrial Revolution and the First Machine Age is the potentiality that occurred after the destruction of the First World War and subsequent wiped out or weakened economic and political ideologies that dominated for many years.

Although the two world wars are periods of stagnation in many aspects, military research has led to remarkable outcomes in the research and the development of technology, especially communication tools. The need for military communication equipment resulted in immediate action to improve the quality and quantity of communication. Some of these innovations range from long-range cables, high-powered mobile radio sets, and short-range navigational systems to the most complex ones: televisions, data-processing devices, and "electronic brain" equipment (computer).[53] Most importantly, after the World War II, the diffusion of military technology (especially communication technology) had vast repercussions on industry, economy, and society, thereby resulting in a new revolution in the industry, which is regarded as the Third Industrial Revolution. The third Industrial Revolution that continued with the 'Digital Revolution' and 'information age' was also related to the similar concepts in sociology and economics such as post-industrial society, information society, knowledge economy, de-industrialization, and network society.

In the post-war period, advancements in information and communication technologies with the research and developments in microelectronics and those in the military field and science led to new conditions in many spheres, especially in

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[52] Reyner Banham, *Theory and Design in the First Machine Age, 2nd Ed.* (New York, Washington: Praeger Publishing, 1967), 10.
[53] G. Raynor Thompson and George I. Back, "Military Communication," *Encyclopedia Britannica*, https://www.britannica.com/technology/military-communication Accessed 25 Apr. 2020.

industry. With the spread of the computer; mechanical technology and manufacturing, which is the foundation of industrial society, were displaced by the "intellectual technology" (based on mathematics and linguistics), which uses algorithms (decision rules), programming (software), models and simulations that also provided the automation in production.[54] The conception of technology which was woven with the embodied elements of industry (machinery, steam engines, textile machinery, steel, railroads) shifted from the factory floor, disembodied and turned into a systematical organization of knowledge and thus automation of production. The transition from machinery manufacturing to the new status of the industry was characterized by the R. Kaplinsky in his *Technology and Development in the Third Industrial Revolution* as the movement from the period of machinofacture to systemofacture.[55] This new mode of production is distinguished from the rest by some kind of coordination or organizational system that gathers, processes and transmits the information that flows over the factory floor and thus mediates between the spheres of design and manufacture. D. Bell saw the new communicative system as an infrastructure of the new society, and he wrote:

> The infrastructure of industrial society was transportation—ports, railroads, highways, trucks, airports—which made the exchange of goods and materials possible. The infrastructure of post-industrial society is communication: cable, broadband, digital TV, optical fiber networks, fax, e-mail, ISDN (integrated system digital networks, combining data, text, voice, sound, and image through a single channel).[56]

Industrial society, based on "a labor theory of value," enabled industry advancement by seeking labor-saving alternatives. Whereas post-industrial society and science-based technology are based on the "knowledge theory of value," and in this new economy, knowledge is the primary source of its innovations and developments.[57]

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[54] Daniel Bell, "The Axial Age of Technology" in *The Coming of Post-Industrial Society: A Venture in Social Forecasting* (New York: Basic Books, 1999), 15.
[55] Charles Cooper and Raphael Kaplinsky, "Technology and Development in the Third Industrial Revolution," *The European Journal of Development Research*, vol. 1, no. 1, (1989): 5-37.
[56] Daniel Bell, in *The Coming of Post-Industrial Society: A Venture in Social Forecasting* (New York: Basic Books, 1999), 17.
[57] Ibid., 19.

Therefore, as the knowledge became a valued capital, the economy shifted its focus from the production of goods to provision of service and information. Post-industrial society then followed a process of de-industrialization as a result of globalization at the end of the 20th century. Due to social and economic changes, it is the phenomenon of reduction, re-localization, or removal of industrial activities, especially in developed countries. While the workers of industrial society were directed to new alternatives such as finance, information, and service sector, manufacturing was moved to lower-cost sites or overseas where the labor force was cheap.

Table 2.5. Technical Aspects of Industrial vs Post-Industrial Age.

	Industrial Age	***Post-Industrial Age***
Technical Element	Machine-Tool	Digital-Tool
Production Technique	Mechanic	Intellectual
Producer Type	Mass Producer	Lean Producer
Worker Class	Manual Worker	Service Worker
Production Location	Factory	Office
Common Resource	Raw material	Information
Economic System	Industry	Service
Technological Transformation Pattern	Sequential	Constant

Another rupture of the Third Industrial Revolution was in the status of knowledge. This condition of knowledge which is still transforming today, was investigated by French philosopher and postmodern theorist Jean-François Lyotard (1924-1998) in 1979 as a new condition of the Second Machine Age. In the book, *The Postmodern Condition: A Report on Knowledge*, Lyotard analyzed the process perceived in the post-industrial society and the status of knowledge that transformed with the advent of the computer. According to his investigations, research and the transmission of the information and thus the status of knowledge altered as a consequence of 'computerization' as he called it. Knowledge, which was a narrative for a long time, became scientific in the modern era due to concerns about the legitimacy of knowledge. However, in the post-industrial period, both the status of knowledge and its legitimacy transformed and differentiated from scientific and narrative knowledge. According to J. F. Lyotard, the source of this change caused by the new revolution is a "variable in the status of knowledge." Consequently, the information society, which emerged from developments in information technology and computers, manifests itself as successive fragmentations, divisions, and complexities in information and simultaneous.[58]

2.1.5 Fourth Industrial Revolution | Autonomous Production

The 21st-century industry noticeably reveals itself as cyber-physical and autonomous systems fed by the widespread use of information and computer technologies and their development and transformation with the contributions of altered society. On the other hand, a new alteration from the Second Machine Age, the age of 'domestic electronics and automatic machines' to a new Machine Age, can be observed due to the consequences of recent transformations. The most evident sign of this transformation is the shift from unmanned production conditions of stable machines in factories to; firstly, the developed limb movement (through a robotic arm and leg) with robotics; secondly, the off-factory work capacity and in-site production; and thirdly, re-established integration of human to machine (H2M) relationship.

Like the previous industrial and machine ages, the perceived new machine age and new Industrial Revolution have impacted and transformed society and all other

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[58] Jean-François Lyotard, *The Postmodern Condition: A Report on Knowledge*, 1979.

related systems throughout the beginning of the 21st century. As this thesis aims to understand the condition of 21st-century industry and architecture and their relation, a deeper investigation of the perceived transformation of industry is covered broadly in the third chapter and briefly in the fourth chapter.

Table 2.6. The Altered Condition of Post-Industrial Age.

	Post-Industrial Age	***21st Century***
Technical Element	Digital-Tool	Robotic Limb-Tool
Production Technique	Automatic	Autonomic
Producer Type	Lean Producer	Custom Producer
Worker Class	Service Worker	Knowledge Worker
Production Location	Office	Off-Factory
Common Resource	Information	Big Data
Economic System	Service	Virtual
Technological Transformation Pattern	Constant	Reticulated

2.2 Tracing the Influence of Industrial Revolution upon Architecture

> In the 1960s and 1970s, many architects who were so unsatisfied with industrial mass production said: ‘This cannot work. This is against the human mind and body. But if you made this statement in 1970s, there was no alternative to industrial mass production in economies of scale. If you wanted to make something cheap, you had to use mass production. That was 1977.[59]

[59] Gramazio, Fabio, Matthias Kohler and Silke Langenberg. "MARIO CARPO IN CONVERSATION WITH MATTHIAS KOHLER" in *Fabricate 2014: Negotiating Design & Making,* (London: UCL Press, 2017), 15. Retrieved from JSTOR

Italian author and architect L. B. Alberti's separation of design and making in the Italian Renaissance re-defined the architecture profession. Architects were not "makers" anymore like they were in Middle Ages or “homo faber”[60] as Richard Sennett also indicated in his book *The Craftsman*. Meanwhile, the division of architectural practice as the architect, the thinker, and designer of the practice, and the producer, who is only the maker of the design, presented a similar process in the Industrial Revolution with the division of labor. The standardized mass production and the assembly line brought by the mechanization of production also caused a transformation in which the worker's performance was favored rather than the knowledge or the learning experience. Similarly, the architect's authority, once changed in the Middle Ages, continues to decline with increasing engineering complexity with industrialization and information complexity reaching its peak with computerization. Another discipline comes into prominence as one part of the architecture, "craftsmanship," which combines mind, body, material, and the knowledge learned with experience while bringing forth a totality with meticulous attention to detail. At this point, not only the craftsmanship's "making by hand" aspect, the methodology in the production process, and the established dialog between object and subject provide a comparable surface that concerns architecture.

Since the onset of the Industrial Revolution, with the continuous evolution of machines, the language of architecture has transformed simultaneously. Beginning from the machine _used as a tool_ to the machine _used as a worker_, created diverse consequences in the process of production. Mechanization entered into the manufacturing world with adornment toward the clean, perfect, and beautiful end product. In the 19th century, with the Second and Third Industrial Revolution, mass production spread into the mechanized manufacturing system, which popularized the significance of the quantity of goods rather than its quality. In such an accelerated

[60] Richard Sennett, *The Craftsman* (New Haven: Yale University Press, 2008).

mass production system, standardization becomes a social issue regarding lacking quality, value, and meaning.

The transformation continued with the computerization and inclusion of CAD software in the design process. Digital-tool language caused a transition in the expression of the object to a smooth and curvilinear surface. On the other hand, CAD has made the architect's drafting and modelmaking process into a series of digital techniques. Such reduction of traditional 'hand and mind' design activity to the 2D digital image has impacted the architect's perception of space and scale and, therefore, the architecture.

The way to embody the CAD design in harmony with the material has also been enabled with CAM technologies. High technology fabrication techniques (CNC Milling, Laser cutting…) have affected the integrity and expression of the design with the material. In recent years, robotic fabrication, which has been on the agenda, is regarded as another industrial development that transforms architecture as a second phase of CAM technology. Robotics, which is included in the research and practices of architects, bridges the gap between design and making, increasing the architect's authority over the architectural process for the first time since the Middle Ages.

2.2.1 First Machine Age and the Inclusion of Mechanic Machine

In the most general framework, the Industrial Revolution is the process of transition in the late 1700s from hand production to machinery; to the production involving iron and chemicals; to intensive use of steam and water power; to a new system that both concerns manufacturing and architecture; to the mechanized factory systems. The integration of machines into society has also led every industry to urge to adapt technological development. In the following years, the development of steel and concrete systems is followed in heavy industry.

In the machinery and iron industry, which were the main assets of the Industrial Revolution, the building materials iron frame, wrought iron, and cast iron profoundly influenced the engineering forms and architecture of the period. J. Wilkinson's developments in working iron systems allowed the design and construction of the first cast-iron bridge in the 1780s.[61] The use of iron as a construction material continued in bridges, roads, and warehouse structures, both concerning disciplines of engineering and architecture. In the early days of the industrial transformations, the form and language of the buildings remained faithful to the details, such as lion figures, brick pavements, and gothic arches.

Figure 2.1. The Britannia Bridge Entrance with Lion Figures, 1846. Retrieved from https://upload.wikimedia.org/. Accessed 9 Jan. 2022.

With the sudden emergence of the glass sheet in the 1850s, the "fully glazed structure" was immediately used in architecture.[62] This technique, which was first used in botanical gardens, was later used as a covering system for wide openings in train stations. For instance, in Turner and Joseph Locke's Lime Street Station, the roof is covered as it is used in botanical gardens, but when the structure's closure and its relationship with the ground are considered, the brick wall comes to the fore.

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[61] Kenneth Frampton, *Modern Architecture: A Critical History, 3rd Ed.* (London: Thames & Hudson, 1992), 29.
[62] Ibid., 33.

Regarding architectural language in a similar condition, K. Frampton writes the following quote from *Traité d'architecture* written by an engineer L. Reynaud, regarding the 'representation' issue that was recognized at that time:

> Art does not have the rapid progress and sudden developments of industry, with the result that the majority of buildings today for the service of railroads leave more or less to be desired, be it in relation to form or arrangement. Some stations appear to be appropriately arranged but having the character of industrial or temporary construction rather than that of a building for public use.[63]

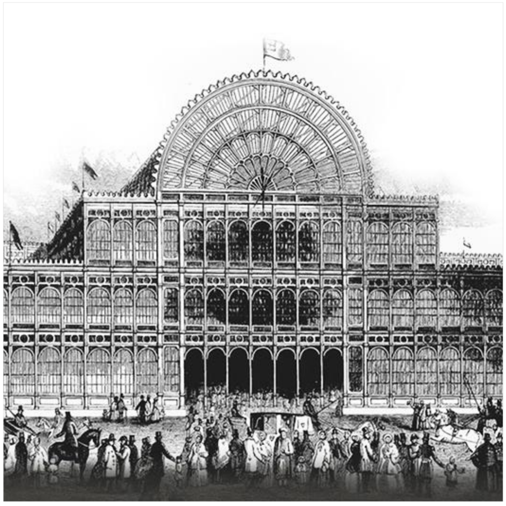

Figure 2.2. The Crystal Palace, London, United Kingdom, Joseph Paxton, 1851. Retrieved from https://www.metalocus.es/. Accessed 9 Jan. 2022.

Like train stations, exhibition structures became the buildings where engineers could have experiments with glazed structures. The Crystal Palace, built-in 1851 by the garden designer Joseph Paxton, is an example of these engineering trials. The structure of Crystal Palace was influenced by the technical, mechanical, and structural details associated with its construction process. However, being unprecedented scales brought unforeseen problems related to its ventilation. Later, increasing competition from industry led to the proliferation of exhibition structures where machines were exhibited. At some point, these structures where machines were exhibited turned into structures that exhibit themselves like machines. That

[63] Ibid., 33-34.

transformation also manifests itself in two French engineering in the 1880s: one is "Galerie des Machine," designed and erected by architect Ferdinand Dutert and engineer Victor Contamin; the second is the wrought-iron tower Eiffel tower by engineer Gustave Eiffel.

The main principle that gives form to machines is their functional efficiency. Machines ranging from steam engines to airplanes and their components are joined and assembled in accordance with technical and mechanical working principles. In such a design process, it is not possible to remove and discard any part or it is not expected to be added a random component to the system without any functional concern. The primary purpose of the machine design is to provide functionality. Later, this functionality of the machine creates a formal composition and language, a particular harmony and rhythm over the mechanic machine. The machine's design and production logic reveal themselves as the "machine aesthetics." In architecture, while it can be observed as the intensification of the effect of functionality in the design process during modernism, it has also been observed as an architectural language. That influence can be seen as a manifestation of architectural elements, constructional structure, materials, infrastructural details, in short, its tectonics, as an undisguised construction and as a brutal frankness of materials.[64]

The transition from hand production, aka craft production, to machinery had a broad repercussion that shook the production itself from its foundation, language, process, environment, and even meaning. Machine's role in making beautiful, perfect, and clean end-products in such a short time that could not be done by hand took the craft production to an arguable defeat. Craft's inevitable condition was caused not, of course, by the fact of its outstanding quality or uniqueness but by the fact of its one-of-a-kind end product. The components that craftsmen produced by hand caused intricate complications to resolve, especially in crafted vehicles at that time, when their maintenance, partial replacement, and repairment were taken into account. In

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[64] Reyner Banham, *Theory and Design in the First Machine Age, 2nd Ed.* (New York, Washington: Praeger Publishing, 1967).

the book *The Machine That Changed the World*, J.P. Womack, D. T. Jones, and D. Roos put forward the condition of the automotive and motor industry and the struggles that occurred from its *craft* origins to *mass production.* While emphasizing the problematic aspects of both of these production methods, they concluded the study with an emphasis on "lean production," which the industry shifted to in the 1950s and 60s, reviving the motor industry.[65]

Figure 2.3. Craft Production, Mass Production Comparison, Medieval Settlements, Sorano, Tuscany (Left), Urban Settlements of Modernism, The Pruitt–Igoe Complex (Right). Retrieved from https://upload.wikimedia.org/, https://images.adsttc.com/. Accessed 9 Jan. 2022.

As for the craft origins of the production, "The craft producer uses highly skilled workers and simple but flexible tools to make exactly what the consumer asks for – one at a time."[66] Vernacular architecture with skilled builders that work with the material available in certain regions could be an example of this system. Skilled builders, who were not educated architects, were capable of what the consumer/client asked for and taking immediate, local actions. However, like other artisanal products, craft production was insufficient to meet the demand and economic condition of the new world population that started to grow with the Industrial Revolution. For that reason, another producer advanced, which is "The mass-producers" that "uses narrowly skilled professionals to design products made by unskilled workers tending

[65] James P Womack et al., *The Machine That Changed the World* (New York: Macmillan Publishing Company, 1990).
[66] Ibid., 12-13.

expensive, single-purpose machines."[67] Even though the mass-production ended up with a continuous, still moving assembly line that provided a final standardized product, the positive aspect attributed to the production system was the interchangeability of parts and the easy attachment of these parts. Nevertheless, architecture is not a product that needs to be repaired, disassembled, or interchanged. Therefore, the favorable aspect did not apply to architecture. However, standardization, as a negative aspect of the mass production, has become a principal issue in architecture and architectural theory.

Figure 2.4. The Architectural Language of the First Machine Age, Bauhaus Building, Dessau: the Student Accommodation Block, Dessau, Germany, Walter Gropius, 1926. Retrieved from https://archdaily.com/. Accessed 9 Jan. 2022.

Another development that fundamentally affected industrial society was reinforced concrete, which began to be developed intensively by François Hennebique between the 1870s and 1900s. The French builder, Hennebique, overcame the problems regarding the reinforced concrete system and enabled the integration of reinforcement, monolithic joints, and cement that is very close to what is used today. After the trials started with the mill and road structures, reinforced concrete became the primary material for every building type in the early 20th-century architecture.

[67] Ibid., 13.

The sophisticated wide spaces explicitly designed for reinforced-concrete technology by French architects Anatole de Baudot and Violler-le-Duc between 1910 and 1914 were too vast for the technology of that early period. However, Max Berg's iconic "Centennial Hall" represents an intricate dome design built with a series of the reinforced-concrete truss system. In the 1910s-1920s, the reinforced concrete frame became a standard technique in architecture while enabling a massive building blocks like architect Matte Trucco's "Fiat Factory" it gave the foundations of Le Corbusier's "Maison Dom-ino," which led to the emergence of a modern language in architecture. In the following decades, the reinforced concrete construction technique in architecture has developed with engineering applications, especially on bridges like wide parabolic or ribbed arches, and bow-string techniques, and has become the most economical construction technique.[68]

As a result, the language of construction that emerged with all these technical developments, the "materiality of the functional form of architecture"[69] and the "honesty" of expression constituted the characteristics of modern architecture in this period.

2.2.2 Second Machine Age and the Inclusion of Computer Machine

Along with factory machinery and chemical production, which are the two main elements of the Industrial Revolution, architecture and engineering have integrated throughout the First Machine Age. The Second Machine Age, namely the age of Machine-Design, which Reyner Banham called the age of "domestic machines and synthetic chemistry,"[70] was harshly introduced as "an age without ideology, and its

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[68] Kenneth Frampton, *Modern Architecture: A Critical History, 3rd Ed.* (London: Thames & Hudson, 1992).
[69] Maria Voyatzaki, "Computing Architectural Materiality: The Hyper-Natural Aspirations of the New Paradigm," *International Journal of Architectural Computing* 7, no. 4 (December 2009): 555–64, https://doi.org/10.1260/1478-0771.7.4.555.
[70] Reyner Banham, *Theory and Design in the First Machine Age, 2nd Ed.* (New York, Washington: Praeger Publishing, 1967), 10.

books are not theoretical...they are more likely to be collections of images with a bland, soothing text laid like wall-to-wall Berber carpet between them"[71] by his student Martin Pawley in his book *Theory and Design in The Second Machine.* The spread of media that was unprecedented in its time, such as photography, print media, cinema, and television, enables people to communicate unilaterally. However, these techno-cultural paradigms reveal their character with mass consumption of image and material culture accordingly. In architecture, a similar condition emerged with the architectural books and magazines. The projects were treated as a "collection of images" without any content of plan, principles, and applications by journalists and advertisers, not architects. According to M. Pawley, architects had also educated themselves to be visually oriented rather than theoretically oriented and let architecture be "reduced to imagery."[72] Therefore, the willing abandonment of ideology, reason, and logic created an architecture that appeared as a deposit of styles for any architect to replicate.

Figure 2.5. The Architectural Language of the Second Machine Age, M2 Building, Japan, Kengo Kuma, 1991. Retrieved from https://www.wallpaper.com/. Accessed 9 Jan. 2022.

[71] Martin Pawley, *Theory and Design in the Second Machine Age* (Oxford: Blackwell, 1990), 4.
[72] Ibid., 1-11.

After World War II, military developments advanced communication technologies and enabled the invention of the computer. The computer machine, which also characterizes the beginning of the information age, has an extraordinary impact on architecture compared to previous machines that influenced the fabrication process. Machine-design, also known as computer-aided design (CAD), is the inclusion of the computational machine in the design processes. With the influence of the French aerospace industry, computational technologies were initially used in the design process of motor cars and ships before architecture, before Frank Gehry’s Office made its application for complexities in curvilinear construction.

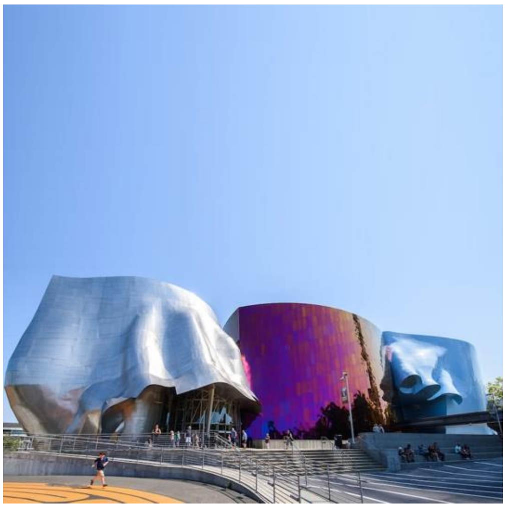

Figure 2.6. The Influence of the Digital Tools on Aesthetic Skin, The Museum of Pop Culture, Seattle, Frank Gehry, 2000. Retrieved from https://en.wikipedia.org/. Accessed 9 Jan. 2022.

Although the computer-aided design (CAD) has begun to change its appearance, it has not been reflected in the entire architectural object. Regarding the issue, Pawley defines *American architecture* as "badge engineering" or "signature architecture" and compares the car without a badge to architecture without a facade/skin. Pawley explains the division of the representative unity of architecture into structure and appearance as follows, "The cruel truth is that, despite their apparent popular success, all post-Modern architectural achievements are isolated from the major technological developments."[73] In addition, Voyatzaki also points out that the "building elevation" has no longer been an "inseparable part of the whole."[74] The reflection of the Industrial Revolution of the period is therefore reduced to the expressive body of architecture that unfolds to the city and informs it. In addition to the form, on the other hand, the separation of skin from the functional body of modernism enhanced the significance of material variation.

The architectural design, which has become an intricate process with the computer's inclusion, has reached the point where the architect cannot manage it individually. This complexity of buildings, together with infrastructural details and growing scales, led to the emergence of new disciplines such as "Project Management" and services such as "Design Consultancy."[75] In parallel with the negativity of the emergence of a new branch of labor on the construction cost, the production of architectural drawings comes to the fore with the potential to reduce these costs. This potential was based on the assumption that the drawing process might be automated in the future with CAD. Even though it has not happened yet, the architect's role was reduced and was divided into an organizational network.

Turkish architect and city planner Raşit Gökçeli attributes this condition to superior financial and stock market performance in parallel with the developing digital technologies in this period. According to his research, with the emergence of globalization and neo-capitalism, the relationship between production and capital changed, and physical production lagged behind the financial sector and its transactions. In the meantime, real estate had to acquire a liquid character and was transformed into a *money capital* by the economic circle with "mortgage" and other similar systems. The skilled designer/maker architect was also affected and transformed by this cycle and had to treat the building as an investment project in

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[73] Martin Pawley, *Theory and Design in the Second Machine Age* (Oxford: Blackwell, 1990), 1-11.
[74] Maria Voyatzaki, "Computing Architectural Materiality: The Hyper-Natural Aspirations of the New Paradigm," *International Journal of Architectural Computing* 7, no. 4 (December 2009): 555–64, https://doi.org/10.1260/1478-0771.7.4.555.
[75] Ibid., 5.

order to respond to the demands of finance and capital. The architect, who is regarded as skilled labor, now had to master project time and cost management, real estate evaluation and economic value, project management, and coordination issues.[76]

For this reason, the *precariousness of skilled labor* occurred that affected the whole system of organization, and indeed the skilled laborers as architects and urban planners. In parallel with this condition, the "Continuous Professional Formation" phenomenon, which aims to equip professional groups with current technological conditions and working organization, established another transformation. The increasingly tricky training and working process of skilled labor has caused both attrition and separation in the profession. In Turkey, these transformations in architecture and urbanism emerged in the form of different fields such as expertise, building inspection, occupational safety, and separate professional chambers and unions. As a result of all these alterations, the architectural profession has been under the threat of marginalization and assurance, both from the perspective of finance and professional divisions.[77]

In the end, the separation of the facade of the building, which has received a communicative and expressive significance, from the entire architectural structure, and divisions of professions into service-based definitions characterizes post-modern architecture influenced by the information technologies of the industry.

2.2.3 Third Machine Age and the Inclusion of Robotic Machine

The architect's authority and the range of duties are not known for being quick to alter. From the transformation of the architect's competence in the Middle Ages to the role of designer, as Vitruvius stated, architects had to have skills for every construction process and, of course, had to have knowledge of every branch. After the Industrial Revolution, architects were fallen back on regarding the knowledge of

[76] Raşit Gökçeli, *4. Endüstriyel Devrim ve Mimarlık* (İstanbul: Verita Yayınları, 2020).
[77] Ibid.

construction and the building construction technology developed, with the first experiments of the engineers of the period. In the meantime, the authority of the builder has spread to many disciplines, such as electrical and civil engineering. It has reached a point where almost a sole authority cannot be reached in the architectural process. With the information revolution, the practice of architecture began to be associated with the service sector, which has led to the proliferation of disciplines such as project management and consultancy. Nowadays, as robotic machinery and its limb (arm, leg) technology are involved in the process, the observed transformation in the authority of the architect over the whole practice has become visible with the ongoing experiments and projects.

Figure 2.7. Emerging Architectural Language as the Third Machine Age. Tecla House, Italy, Mario Cucinella Architects, 2021. Retrieved from http://www.itsnicethat.com/. Accessed 20 Jan 2022.

As computer machines transformed the architectural design process, the robotic machine has affected its construction process. It has turned into a new element that indicates the inclusion of the builder under the authority of architecture. As the in-situ robotic fabrication technique revealed, machines are freed from factory boundaries. These machines were sometimes shrunk to the size of domestic electronics and used for hobby purposes by any individual, and sometimes for one-hand construction of a design with immense dimensions. Today, complex and, therefore, costly architectural constructions are in trend. Even the number of the responsible team member in the process of such design have increased incomparably more than in previous periods.

Figure 2.8. 3D Printed Concrete Book Cabin, Shanghai, China, Professor XU Weiguo's Team, 2021. Entrance with a patterned surface and experiment with exterior form (Left), top perspective with openings for light and entrance (Right). Retrieved from https://www.archdaily.com/. Accessed 20 Jan 2022.

Therefore, the architect, who holds the authority of the whole process with robotic fabrication, enables a different alternative with the altered material science and altered space of the present technology. Since this thesis aims to understand transformations in architecture within the Fourth Industrial Revolution, the analysis of the relationship between architecture and the current industrial technology is explained in further detail in the fourth chapter.

CHAPTER 3

TRANSFORMATIONS IN INDUSTRY

Since the Industrial Revolution, a series of developments occurred throughout history, beginning with the steam engine that initiated mechanization and continuing with computerization which influenced automatic manufacturing. It has been about 50 years since the invention of the computer, whose continuous influence has never ceased. Programmed machines took over jobs, causing technological unemployment. Digitalization played a role in the shift in the business sector and triggered processes of de-industrialization with the onset of the service sector. The industrial society, which began with the struggles of the working class, has already started to engage with the new working conditions like a home office, virtual workplace, and flextime. Meanwhile, the terms digital culture, the digital, and the virtual economy have been used to describe the period since the 1990s.

3.1 The Post-Industrial Condition

The First Industrial Revolution, which was set by the railroads and the invention of the steam engine, started mechanical production in 1760. Then, in the late 19th century, the Second Industrial Revolution, which led up to mass production, was triggered by the inventions of electricity and assembly lines. Lastly, in the 1960s, the Third Industrial Revolution started with "the development of semiconductors, mainframe computing (1960s), personal computing (1970s and 80s), and the internet (1990s)."[78] followed by an automatic production with the programmable and systematical process.

[78] Klaus Schwab, *The Fourth Industrial Revolution* (Geneva, Switzerland: World Economic Forum 2016), 11.

Looking at the last 20 years, the debates about the current period, whether it is the third industrial period or the fourth or fifth period, are continuing. While academics and professionals still argue over the topic and insist on the fourth one, the economist and social theorist Jeremy Rifkin, in his book *The Third Industrial Revolution*, claims that we are still in the third one even with emerging internet-based mobile devices and intelligent buildings.[79] However, the ongoing technological breakthroughs and developments, which are characteristic of the last 20 years, cause an unprecedented situation that needs to be discussed and understood. Due to the constant advancements, it is hard to define a general definition in such an ever-changing period. In the meantime, many thinkers are influenced to give definitions to these transformations. Some of the defined alterations of new society vary from Daniel Bell's "post-industrial society" definition to "information society," "post-modern society," "network society," "post-economic society," "post-scarcity society," "knowledge society," "personal service society," "post-capitalist society," "the technetronic society," "home-centered society."[80] All these different concepts agree, at the very least, that a new revolution is taking place. In his book *The Fourth Industrial Revolution*, K. Schwab emphasized the overlooked scope of the new revolution:

> We have yet to grasp fully the speed and breadth of this new revolution. Consider the unlimited possibilities of having billions of people connected by mobile devices, giving rise to unprecedented processing power, storage capabilities and knowledge access. Or think about the staggering confluence of emerging technology breakthroughs, covering wide-ranging fields such as artificial intelligence (AI), robotics, the internet of things (IoT), autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing, to name a few.[81]

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[79] Jeremy Rifkin, *The Third Industrial Revolution: How Lateral Power Is Transforming Energy, the Economy, and the World* (New York: Palgrave Macmillan, 2011).
[80] Krishan Kumar, *From Post-Industrial to Post-Modern Society New Theories of The Contemporary World* (Malden, MA: Blackwell, 2005).
[81] Klaus Schwab, *The Fourth Industrial Revolution* (Geneva, Switzerland: World Economic Forum 2016), 7.

The mass-production and automation process of the 20th-century industry has developed into a new systematic relation with ground-breaking developments such as the invention of the first microcomputer in 1971 and the establishment of the Apple Computer Company in 1976. For the 21st century, it is necessary to mention an altered condition of the emerging technologies of robotics, autonomous production systems, and cyberspace and cybernetics. Epochal developments include the Internet of Things (IoT) in 2000, the cellular transport system in 2010, and autonomous interaction and virtualization in 2020. Results of these developments are used to derive design principles for new industrial conditions. M. Hermann, B. Otto, T. Pentek's study on Industry 4.0 gathers six design principles: Interoperability, Virtualization, Decentralization, Real-Time Capability, Service Orientation, Modularity.[82]

- *Interoperability* is the term that represents the condition of today's over-connective digital environment that enhances the communication between and within the variable type of businesses, (Health, IT...) communities, and even politics. The principle can be exemplified with twitter being a political space or contagious tracking application that integrates with every individual's data.
- On the other hand, *virtualization* is the translation of every physical information regarding to the condition of a business to a digital document, so that the translated data can be used to analyze and demonstrate the operations, reflections.
- *Decentralization* is a primary principle that relies on multiple subcomponents rather than a centralized computer. The aim of such multi-tasking in between components is to release one computer's automatic control and develop an autonomous judgment process.

[82] Hermann, Mario, Thomas Pentek and Boris Otto. "Design Principles for Industrie 4.0 Scenarios," *2016 49th Hawaii International Conference on System Sciences* (Jan. 2016): 3928-3937.

- The possibility of an autonomous process is due to the *real-time capacity* of the contemporary digital environment. The accelerated development of network speed, IoT, and cyber-physical systems (CPS) enables a real-time information transfer between 'human to human,' 'human to machine,' and last but not least, 'machine to machine.'.
- *Service orientation* is the service-oriented attribute of today's condition that allows smooth and accessible communication between service businesses and customers.
- With the *modularity* of contemporary industry, a flexible adaptation is possible in case of new transformations, demands, and necessities.

Due to the deeply interconnected, multifaceted structure of new developments, the emerging developments are evolving at ramified and diversified pace rather than a linear one. The unprecedented structure of this new revolution also proves another specific point that sets it apart from the pre-conditions. However, it is also arguable whether a new revolution occurred or not. An opposite sociological perspective comes forward by claiming that the contemporary condition is just an accelerated extension of industrial society. All this debate is actually due to the technological determinist approach of social theorists. Moreover, the so-called change and alteration are already in the essence of industrial society.

Despite opposite opinions, it is hard to deny recent technological condition that is developing at a pace that society is not accustomed to, the multi-layered organization and functioning caused by these chain reactions, and lastly, the multi-linked condition that ultimately spread throughout the world. New principles of industry not only alter the economic condition of humankind but also cultural, political, and indeed social. Integration of every individual through the current digital environments inevitably leads to more comprehensive influences that can expand the job definitions to globalized competition.

The reticulated and multi-linked condition of the age is the principal transformation in any industry from technology to digital technology. This provides the initial principle of period: being smart. For the last two decades, industries having a digital transformation rather than a physical, relying on software rather than hardware. The advantages of readily available constant information, today's coordinated actions, and collaborative decisions seem to be a time-saving demandable option. Thus, although objects and end products are physical, the main goal of any industry has been to develop and digitally integrate the production process rather than the product itself.

One of the other principles of the period is the "decentralized decision," which is the characteristic of CPSs to make a decision to perform their task autonomously. These new developments enabled a network of communication between human-machine, machine-machine, and machine-resource that caused "a paradigm shift from centrally controlled to decentralized production processes."[83] It is the period of a non-living intelligence that knows its current status and goals through its production history, which can also transfer and direct the next phase of production.

In the end, with the popularization of the usage of cyber (web, social network, data, apps) – physical (robotics, computer, mobile, tv) systems, and IoT; the accelerated alteration become more complicated with the participatory, interactive, collaborative mode of production which progress over a domain with multiple and variable inputs. The production period with one hand and one book are long gone now and transforming into more complex systems of organizations with vast data of impacts of such variable inputs.

3.2 Globalization and Virtual Economy

The cultural and social progress developed due to industrialization can be expressed in a series of fundamental ages and economic systems. The *pre-industrial age* was an economy dominated by manual labor, livestock, and agriculture. While it was an

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[83] Mario Hermann, Thomas Pentek and Boris Otto. "Design Principles for Industrie 4.0 Scenarios," *2016 49th Hawaii International Conference on System Sciences* (Jan. 2016): 3928-3937.

economy driven by factories producing goods for the *industrial age,* it was based on service and knowledge labor through computer and media tools for the *post-industrial age* or the information age. Looking at the current developments, a new paradigm is mentioned caused by a high-speed network, virtual sector advancements, graphics technologies, and substantial data storage. In this regard, a shift is argued from the information age and its economy based on theory, analysis, and rational thinking to a new economy based on creativity, imagination, and user-generated content (UGC) and therefore to a new epoch, "the imagination age."[84] However, just as the efficiency of the industrial economy has not decreased with the information age, the service sector has not lost its effectiveness in this new era of imagination.

The principal component of the current economic condition, the service sector, was in a secondary or tertiary position in pre-industrial society with domestic services and in industrial society with transportation and financial services. The altered condition in terms of the economy emerged with the shift from these low-priority positions to the human service that includes health, education, social service, and professional services mentioned under mass media, public health, consulting, and real estate. This transformation is interpreted as the alteration of society from an industrial society to a post-industrial society, from the manufacturing of goods to the provision of services.[85] As a matter of fact, when we take a look at the economies of developed countries, even though there is a crisis in traditional industries like automobile, textile, construction; new industries like computers, electronics, biotechnology, VR, robotics that is based on information/knowledge are improving sharply. Furthermore, many traditional industries, including construction, were also impacted by the COVID-19 pandemic, which resulted in an urge to engage their

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[84] Charlie Magee, "The Age of Imagination Coming Soon to a Civilization Near You," *Second International Symposium: National Security & National Competitiveness,* Vol. I, (1993): 95-98. Retrieved from Web Archive, https://web.archive.org/

[85] Daniel Bell, *The Coming of Post-Industrial Society: A Venture in Social Forecasting* (New York: Basic Books, 1999).

operational cycle with the digital systems. As the direction of the new regular shifts to digital, many industries are trying to integrate into this change, despite the disruptions such as loss of momentum and recession. However, according to Toffler, this transformation process, which looks like a recession, is, on the contrary, a restructuring of the techno-economic basis. In other words, it is the process of constructing a new "third wave" economy based on different principles from the old "second wave" industrial economy.[86]

In the meantime, another actor in this process that deals with the concepts post-industrial economy, the information age, the Digital Revolution, and more is globalization. Globalization, with its most general definition, is the new cultural, social and geopolitical condition that emerged with the end of the Cold War in the late 1980s.[87] Historically, globalization made its presence and acceleration with the transportation and communication developments and international trade in the 18th century. However, it can be said that it has reached its current meaning in the last 50 years with the global interaction of societies, ideas, cultures, values, and more. Today, the movement of information with the emergence of the internet, and the movement of people with the advancement of transportation technology, has accelerated globalization of any culture (popular culture, westernization), economy (digital economy, cryptocurrency), politics (global democracy) and even global health (COVID-19 pandemic) in the same manner.

Globalization is one pillar of economic growth today, and before, 'consumerism' was another pillar. It operates on the idea that one's happiness and well-being depend on consuming material goods and services. As Koch points out:

> What constitutes consumer society, or a society of consumption, is social structure and social relations, and image at least superficially defined by consumption, both as activity (consuming) and as social signs (what is consumed). Compared to previous industrial societies, the formation of

[86] Krishan Kumar, *From Post-Industrial to Post-Modern Society New Theories of The Contemporary World* (Malden, MA: Blackwell, 2005).
[87] Murray Fraser, “A Global History of Architecture for an Age of Globalisation, “ *ABE Journal* (Jul. 2019): 14-15. Doi: https://doi.org/10.4000/abe.5702, Retrieved from OpenEdition Journals.

> identities, social structures and status moved from what we produce to what we consume. [88]

Such society is identified with the places they live, clothes they wear, brands they use, and their symbolic value altered the aspect of living inevitably with it. In that sense, the transformation of the environment began with the consumption spaces like malls, shopping centers, streets, and squares.

The altered condition can also be followed by the current economic condition ramified with a new rupture, the COVID-19 pandemic. Interestingly, the new condition that emerged with this new change can also be interpreted as a reminder of the old industrial system. While the service sector, which is the pillar of the post-industrial economy, somehow maintains its momentum through digital platforms and online systems, there has been a significant crisis in manufacturing, consumer goods, and materials (global chip shortage, medical supplies). Electronic consumer goods such as automobiles and graphics cards are affected by the crisis, mainly due to the shortage of semiconductor circuit systems, which has caused complications in the current consumption pattern. Due to the COVID-19 pandemic, the economy's current condition still struggles with these short-chain crises (slow shipment, global shortage…) in manufacturing.

Another economic complication of the contemporary altered condition is the effect of social media. With the online shopping strategies of Instagram, Facebook, and YouTube and the increasing financial information exchange through Reddit and Twitter caused another transformation that should be mentioned. Massive transformations like online shopping and its virtual organization have affected the consumer's everyday life. In the meantime, internet memes as a part of the internet culture spread through whole social media with a remote part to play in the economy. The influencing role of these internet memes promoted the idea of 'stock memes'

[88] Ksenia Katarzyna Piatkowska, "Economy and Architecture. The Role of Architecture in Process of Building the Economic Potential of Space," *Humanities and Social Sciences Review*, Vol. 1, No. 2, (2012): 549-555.

used to manipulate stocks' popularity and impress trade investors who are still young and inexperienced. These are highly speculative as they create a slippery slope for investors who will probably experience heavy losses or big gains. Currently, a virtual economy that is hyped with cryptocurrency, NFTs, and metaverse has also influenced the proliferation of similar environments. For instance, Dogecoin was created as a crypto payment system as a 'joke' by software engineers Billy Marcus and Jackson Palmer out of these platforms. It is also considered the first 'meme' coin that became a legitimate investment option. More importantly, even as a 'meme' and 'joke,' Dogecoin went from the bottom option to one of the top cryptocurrencies with interferences of critical personalities like Elon Musk.

3.3 New Information Society

The norms and habitual structure of the society are re-shaped with each new transformation and new advancements that have broad reflections over production systems. The mode of society affected by each of these alterations was defined repeatedly by social theorists. The agricultural revolution that the hunter society went through, followed by the Industrial Revolution and the information revolution, is summarized as the stages that the mode of society went through until it became the information society. The transition to the information society is accepted as a result of the Third Industrial Revolution, which encompasses the emergence of the computer and the internet. Today, as a consequence of the Fourth Industrial Revolution, which is claimed to be happening with continuous developments such as CPS, AI, IoT, and Blockchain, a new society model is mentioned under the term Super Smart Society. While the term "Industry 4.0" is emerged from Germany, "Society 5.0" draws attention as a term originated in Japan in 2015, introduced by Japanese Prime Minister Shinzo Abe. The striking philosophy of this new society, "which has development goals such as e-learning systems, smart cities, and innovative ecosystem, aims to overcome social problems and improve people's quality of life by integrating the digital environment and the physical environment"[89] is the focus on human-centered understanding.

However, even in the timeline from the information society to the new information society, new ruptures, new branches, and as a result, new layers of society have emerged. While the society is going through the minor transformations from "lean backward" (Television) to "lean forward" (Computer) and to "lean backward" again (Tablet, Smart Phone) according to its technological mediums, it has also become the focus of discussions on the agenda through concepts such as network society, post-work society, mass society.[90]

In the transformed condition of the industry, the class structure of the society is ruptured similarly. In the new society, the workplace where the employee works (home office, work from home) and the work type itself has changed. Drucker defines the 'new class,' He also claims that they will gain a privileged position in the new age where knowledge is the real power, as the "knowledge class/knowledge worker," as also A. Touraine puts forward. It should be remembered that while the definition of factory worker could not be made before the industry, it was not possible to define a 'knowledge worker' before the information revolution. Therefore, it is stated that this new class is replacing the blue-collar worker (factory worker) of the industrial society and the white-collar worker (office worker) of the post-industrial society.

Moreover, the accelerated digitization of the industry and its rapid integration with the media and the new working class that functions as information/data reduces society itself to an information/data source, a kind of new raw material.[91] In this

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[89] Nisa Akın et al., "Akademik Yayınlar Işığında Toplum 5.0 Kavramına İlişkin Bir Değerlendirme" *Atatürk Üniversitesi İktisadi ve İdari Bilimler Dergisi*, Vol. 35 No. 2 (2021): 577-593. https://doi.org/10.16951/atauniiibd.792750, Retrieved from DergiPark.
[90] Sylvia Chan-Olmsted et al., "Towards a Video Consumer Leaning Spectrum: A Medium-Centric Approach". *Nordic Journal of Media Management*, vol. 1, no. 2, (June 2020): 129-85. doi:10.5278/njmm.2597-0445.4600.
[91] Peter F Drucker, "The Age of Social Transformation" *The Atlantic Monthly*, Vol. 274, No. 5 (Nov. 1994): 53-80.

regard, Heidegger's *standing-reserve* should be re-visited. Monitoring and keeping the personal information and experiences (likes, preferences, purchases, click information, locations, etc.) disclosed by the social media user as a raw material resource and presenting and selling it to the digital industry is a typical example of human as a standing-reserve. Today's equivalent of the already existing trio of 'labor, commodity and profit' can be translated as 'humanity, data, and profit.' Zuboff discusses this condition of monitoring under the term "Surveillance Capitalism" and summarizes the new relation between data and society as follows:

> the new data assets were produced through surveillance, they constitute a new asset class that I call "surveillance assets." Surveillance assets, as we've seen, attract significant capital and investment that I suggest we call "surveillance capital." The declaration thus established a radically disembedded and extractive variant of information capitalism that can I label "surveillance capitalism."[92]

3.4 Robotics and Autonomous Production

The "complexity and the division of knowledge" that initiated with the advancements in communication technology in the post-industrial period can now be re-interpreted through the area of robotics. The already divided disciplines have become specialized in their fields and have started to collaborate and integrate to develop complex systematic technologies like robotics and space technology. The intertwining relationship of computer science and mechatronics with other specialized fields like genetics, bio-engineering, software engineering, and disciplines like architecture, art, and other design-based fields has blurred the boundaries between *digital*, *physical*, and *living* that enabled the development of robotics.[93]

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[92] Shoshana Zuboff, "*Surveillance Capitalism and the Challenge of Collective Action,*" *New Labor Forum*, Vol. 28, No. 1 (Jan. 2019): 10–29. doi:10.1177/1095796018819461.
[93] David A. Mindell, *Our Robots, Ourselves: Robotics and the Myths of Autonomy* (New York: Viking, 2015).

The field of robotics has been developing and growing more and more these last 20 years, where industrial robots are included in domestic life and daily life compared to the late 20th century when industrial robots were widely used in the mass and automatic production of both industrial and consumer goods. As in the Second Machine Age, where domestic electrical machines are included in daily life, it is observed that in the new machine age, domestic production machines and autonomous robots are included in daily life with broad social and environmental impacts. The new domestic production machines include various products that vary from production technique to material type.

Figure 3.1. Robotic Assembly of Automobile in Tesla Factory. Retrieved from https://www.theguardian.com/. Accessed 19 Jan 2022.

Although robots predate the technology of the 21st century, it stands out as a product that has become more practical and widespread with today's programming language and AI technologies. Since the development of this field is due to the joint contributions of multiple disciplines, its usage area is also extensive. Robots are mechanical systems that implement human actions and tasks that are difficult, impossible, or time-consuming to perform. Compared to a human workforce, robots can work quickly for hours without being affected by ambient conditions. They can perform many dangerous tasks, from insecure construction jobs to impossible exploration journeys. An industrial robot, for instance, has been able to integrate itself into the existing production cycle of the automotive sector. As for the other areas, fully autonomous robots in surgery, space exploration, and construction have recently begun to be implemented and developed.

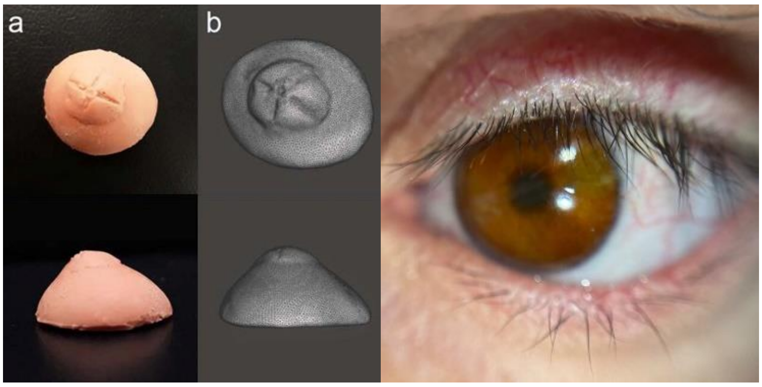

Figure 3.2. 3D Printed Ocular Prosthetics. CAD and CAM Process (left), Printed Prosthetic Application in London, UK, 2021 (Right). Retrieved from https://3dprint.com/, https://assets.newatlas.com/. Accessed 19 Jan. 2022.

3D Printers, which stand out with their accessibility, have been used for the production of prototypes for a long time, and for this reason, it has also been called rapid prototyping. This type of small-scale machine, due to its capacity to be included in every practice with its wide range of materials, continued to develop in various industries, from food to the medical industry. The general principles consist of a 3D digital model created either with CAD or 3D scanner and a file that includes the sliced layers in g-code for 3D printing. Since the whole process takes place through different interfaces and software, it is possible to produce a physical model of any product by a mere producer with particular knowledge. The scale of the intended physical model can limit the 3D printing technique. Since the current working area and volume of the 3D printer cannot be exceeded, the designs of large-scale products are printed in parts and assembled accordingly, so they cannot be produced as a whole. Today, the application of 3D printing that affects society the most is its use in the medical industry, prostheses, organ and tissue transplants. Other than its sectoral usage as an industrial tool, 3D printing has become a customer product that is used by many people for hobby purposes.

Another central stimulus, which influenced the 21st-century social structure and functioning, therefore its industry and production technology, is rapidly rising interconnectivity and advanced organizational systems. With the increasing connectivity, the 2000s distinguished itself from the others as a period in which the digital age became widespread, communication was ubiquitous, and society's relationship with technology became ordinary. These multi-layered communication networks also contain a layer covering all new technology products. New developments such as CPS, IoT, IIoT, cloud storage, and cognitive and artificial intelligence are included in this interconnection system between H2M, M2M, and M2H. Autonomous, unmanned, and even *lights-off factory* processes, which are the new industrial production targets of developed industrial countries, are pursued by utilizing advanced production machines that use these systems and thereby exchanging information, reports, and feedback.

Consequently, the industry shifts to a new advantageous production cycle with the inclusion of advanced network technologies and robotics. The primary advantage of the new production technique is the remote control and monitoring of the production facility via mobile devices. Since the system shares information to the concerned executives through these networks, real-time action and setting management can be done to avoid unnecessary production, material, and energy waste and lower costs. In the meantime, cloud servers and data collection within the system come to the fore as a repository where presets, customer settings, and sentiments are stored, as well as the data of previous experiments and experiences with the process. In addition, the whole operation with production line status can be tracked by other partners and customers, which enhances the transparency from beginning to end. In summary, machine intelligence, advanced wireless-network, and robotics advance the existing condition of the industry to a more *transparent*, *predictable*, *adaptable*, and *data-driven* system.[94]

As a result of the fourth chapter, the industry's digital and physical tool developments in the last 20 years have had a multidimensional impact on society, economy, and culture. These developments, which are claimed to be the extension of computerization and the information age, have also been claimed to herald a new age

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[94] David A. Mindell, *Our Robots, Ourselves: Robotics and the Myths of Autonomy* (New York: Viking, 2015).

of imagination. From a computerization perspective, software and computers appear to advance automation, enabling simultaneous intervention in the production process. With digitization, the transfer of physical data to digital media resulted in transformations of existing codes of objects (i.e., physical book to e-book, turning page to scrolling down). With the addition of the everyday and extensive use of the Internet to the personal computer and digital environment, concepts such as communication, globality, and production have gained new meanings. Every process and system has a virtual counterpart, and the shift from physical to digital has accelerated as well. In the whole progress, *the user* played a role in triggering all developments at the center. Various upgrades (in mobile devices to user interfaces) were made by advancing according to the user type, purpose, and even the place of use. With the development of robotics and the spread of domestic robotics in the last 20 years, the user has become both a consumer and a producer. High-speed Internet and cyber communication have made new virtual environments and organizational forms possible, affecting every aspect of life from production to living beings.

CHAPTER 4

TRANSFORMATIONS IN ARCHITECTURE

The impacts of the still-evolving post-industrial conditions of the Fourth Industrial Revolution on society, economics, and production systems were portrayed in the previous chapter, *Transformations in Industry*. In that respect, *Transformations in Architecture* will be descriptive of the outputs in architectural language and visual expression, spatial conception and perception, construction techniques, and materials influenced by the impacts of technological developments and the Fourth Industrial Revolution. First and foremost, computer, computation, and digital tools were used in architectural practice before the ongoing Fourth Revolution. The digital transformation took place in architecture in the 1990s, ahead of many industries, as it harbors the potential for variability, complexity, and differentiation rather than standardized identical copies of products offered by previous Industrial Revolutions.[95] In this sense, digital technologies in some way have resembled the previous mode of industrial production by increasing productivity/"efficiency" with an aim to "automate design and drafting activities" and, on the other hand enabling a "novel generative approaches that regard computation as an aid to the design process and to explore design ideas."[96]

Digital tools and software have led architectural practice to the experimentation and exploration of "non-Euclidean geometric space, kinetic and dynamical systems, and genetic algorithms," and possible spatial variations and formations.[97] The early representative of digital turn, the Barcelona Olympic Fish, was designed by Gehry's

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[95] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 3.
[96] İpek Gürsel Dino, “Creative Design Exploration by Parametric Generative Systems in Architecture,” *METU JOURNAL of the FACULTY of ARCHITECTURE* 29, no. 1 (June 1, 2012): 207.
[97] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 2.

office in 1992 by utilizing the Dassault's CATIA software. The inclusion of digital continued with many similar approaches, including Bilboa Guggenheim Museum (1993-1997), Disney Concert Hall (1991-2003), and Bard College Auditorium (2000-2003), which reflected the complexity of variably formed surfaces and curves. In the meantime, new visual software and tools like Alias/Wavefront (Maya) and NURBS (Non-Uniform Rational B-Splines) modelers that can create parametric curves and surfaces, came into the architectural practice.[98] These modelling software based on NURBS also led emergence of the "folding" style that was inspired by the "rhizome, multiplicities, assemblage, smooth space, line of flight, deterritorialization, becoming intense, and abstract machine" notions from the Deleuze and Guattari's *A Thousand Plateaus*.[99] The creative potential of *fold* have influenced several architects in the industry of the time, including Zaha Hadid Architects, as the architecture moved from deconstructivism's "logic of conflict and contradiction" to a "more fluid logic of connectivity".[100] MAXXI (1998-2010), Haydar Aliyev Center (2007-2013), Dongdaemun Design Plaza (2009-2011) by ZHA became the precedents of such smooth, curvilinear, "topological" and "rubber-sheet" expressions in architecture of the early decade of digital age.[101]

The design process and logic that passes through specific algorithmic principles, parameters, or notations that manifest free-form geometry with mathematical splines and NURBS is called parametric design.[102,103] On the other hand, just as folding was accepted as a style by Schumacher, the parametric design was also accepted as an architectural style by several architects and theorists with variable movements such

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[98] Patrik Schumacher, *DIGITAL - The 'Digital' in Architecture and Design* London 2019 Published in: AA Files No.76, Architectural Association, 3.
[99] Ibid.
[100] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 3.
[101] Ibid., 21.
[102] İpek Gürsel Dino, "Creative Design Exploration by Parametric Generative Systems in Architecture," *METU JOURNAL of the FACULTY of ARCHITECTURE* 29, no. 1 (June 1, 2012): 207-224.
[103] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 64.

as parametricism and blobism. Carpo defines the movement as *"the style of the blob, also known as the style of the spline or digital streamlining*," demonstrating smooth, curving lines and surfaces due to its relation with "*calculus, the mathematics of continuity*."[104] Today, parametric design in architectural theory is discussed both as a "spline dominant" variation in architectural design and as a new generative design methodology, new logic to the way of making.

In recent years, architectural practices have demonstrated new architecture and digital integration potentials that signal a second digital turn. While these new aspects emerged with the use of new technologies of the Fourth Industrial Revolution, they paved the way for a new transformation in architecture ranging from the intelligence behind the language of design to in-situ real-time fabrication techniques.

4.1 New Possibilities of Architectural Language

Today, architectural theory and practice are moving from adapting to advanced computational technologies, artificial intelligence, robotics, and biology/genetic technologies, to revealing their potential. New methodologies, algorithms, and big data stimulate design language and its grammar from its familiar condition. At the same time, the information age reveals a reverse return to the past by only editing, changing, combining, and re-presenting the accumulated media data.

4.1.1 Post-Digital: The Language of New Digital

Rather than the *postdigital* movement that focuses on being human/humanist in the digitalized society, this thesis uses the definition of *post-digital* as "the period

[104] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 4

following the rise of the digital,"[105] which refers to the beginning of a new turn that differs from the digital age that represents the comprehensive integration of architectural design and construction. The turn represents a transition from "discovering the new ways to create, invent and work together" to "applying those lessons" to the work, profession, and real world.[106] Recently, architects and researchers have attempted to explain the mutual observations on transformation in digital architecture and urban studies and practices by deriving new approaches and understandings. These studies on the language and the visual expression of architecture generally meet a common point. That is, there is a change taking place in the way of digital usage from a design-based integration to more holistic control that narrows the gap between both *theory/practice* and *design/making*. Within these scopes, new paradigms that have reflections on the language of architecture are explained in this section through three concepts that stand out and differ from each other with subtle distinctions:

- *digital materiality* that merges the immateriality of digital and materiality of architecture;
- *digital craftsmanship* that narrows the gap between design and construction; and
- *digital morphogenesis* that provides new organizational, spatial potentials / systems derived from the living organisms.

Firstly, within the context of the digitalization of architecture, the material state of architectural space and the bodily and tactile perception of space has been the center of many discussions. Today, the dimension of this debate has changed with the emergence of *new materiality* in architecture and fabrication, contrary to the envisioned immateriality.

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[105] "Definition of post-digital". *Oxford University Press,* www.lexico.com/en/definition/post-digital Accessed 5 Apr. 2022
[106] Chris Anderson, *Makers: The New Industrial Revolution* (New York: Crown Business, 2014), 17.

Before the case of the dichotomy between material and immaterial that is constituted in the language of architecture, the condition of the material in architecture comes to the fore. In recent decades, the development of material science has made the design industry the focus of radical experiments. P_Wall by Andrew Kudless, as an instance, utilizes the new material knowledge. The traditional wall, which is "smooth, firm, regular and by convention, neutral," becomes a representation of imperfect human skin with "bulges and crevices; love handles and cleavage, folds, pockmarks, and creases."[107] While exploring the potential of cast plaster, Kudless tries to achieve a dynamic visual expression with a static form.

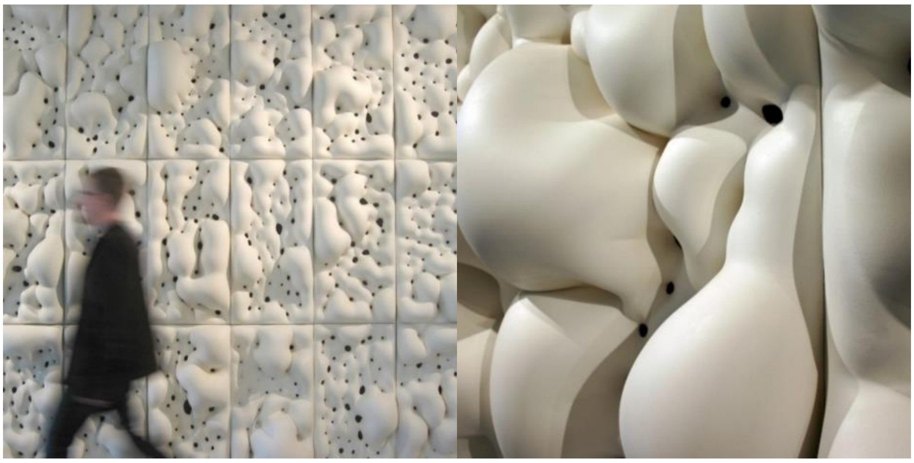

Figure 4.1. New Possibilities of Digital. Banvard Gallery, Knowlton School of Architecture, Ohio State University, Columbus, Ohio, P_Wall, Andrew Kudless/Matsys, 2006. Retrieved from https://www.matsys.design/. Accessed 2 Jan. 2022.

On the other hand, Fabio Gramazio and Matthias Kohler emphasize another alteration in the digital design language that emerged with the attention to *materiality*, which is called digital materiality or new materiality. In this case, the interaction of two opposing domains, material and digital, executed with new digital fabrication processes, enables the material to be "enriched by information" and the material to become "informed."[108] The new materiality generated through the union

[107] "P_Wall (2009) - Matsys," Matsys, 2021, https://www.matsys.design/p_wall-2009.

[108] Fabio Gramazio and Matthias Kohler, *Digital Materiality in Architecture*. (Baden, Switzerland: Lars Müller Publishers, 2008), 7.

of *fabrication* and *programming* presents a manner beyond mere replications, but a diversity through scales, materials, structures, and components beyond the traditional spatial norms.

In addition, the shift of design and fabrication from its traditional relationship to the interactive process between material, data/information, programming, and fabrication let architects control the process from beginning to end. This transformation, which affects the nature of architecture, significantly changes the language of design and, indeed, the role of the architect, who can now be involved in the design and building process through the programming tool. "The course of the design and materialization process" has become an intricate process that "takes on its character little by little" by the central role of the architect.[109]

Figure 4.2. Digital and Material Integration. Winery, Switzerland, Bearth & Deplazes Architekten, Gramazio & Kohler, 2006. Retrieved from https://www.archdaily.com/. Accessed 9 Jan. 2022.

Winery in Fläsch, Switzerland, partially designed and fabricated by Gramazio & Kohler, represents the potential of robotic production and being the intermediary between material and digital. Inspired by the basket and grapes combinations, a *digital pattern* is developed for the facade. Programmed parameters for the whole

[109] Fabio Gramazio and Matthias Kohler, *Digital Materiality in Architecture*. (Baden, Switzerland: Lars Müller Publishers, 2008), 11.

building are created according to this "digital image data."[110] Therefore, the digital materiality does not revolve around the material itself but also encompasses the digital sense of the process that includes the dynamics of the *immaterial*. As in the case of Winery in Flasch, the non-standard design process constituted through the new language with the combination of material (brick) and the immaterial (digital image).

Another paradigm in the digital age that is reflected in the architectural language is digital craftsmanship. Before the mechanization of production, craftsmanship was not a separate concept from other production systems. With the guidance of Glenn Adamson's book, The *Invention of Craft*, Aukje Schukken summarized the case of craft in today's context by pointing out that "Craft" has been viewed as "a rejection of modern technology or a rigid use of traditional production processes" or "'arts and crafts' kind: homemade DIY greeting cards or pillowcases." The meaning we have understood today "was not around until the invention of machine production at the dawn of the Modern Era."[111] Due to the accelerated production of machines, incorporating the craft into this field of making has been seen as an outdated, traditionalist, kitsch practice for over a century. In order to rectify such an understanding, Richard Sennett states that "Craftsmanship may suggest a way of life that waned with the advent of the industrial society – but this is misleading. Craftsmanship is named an enduring, basic human impulse, the desire to do a job well for its own sake."[112]

Richard Sennet, Professor of Sociology at the London School of Economics, extensively analyzed the concepts of craft, craftsman, and craftsmanship in his book *The Craftsman*, describing the ateliers and workshops of the Middle Ages as a system with their own rituals and authority. Ateliers came forward as a "productive

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[110] "Gramazio Kohler Research," gramaziokohler.arch.ethz.ch, n.d., https://gramaziokohler.arch.ethz.ch/web/e/projekte/371.html.
[111] Aukje Schukken, "Craft & Architecture: The Redefinition and Relevance of Craft in Contemporary Production." (Master's Thesis, Delft University of Technology, Oct. 2016), 23.
[112] Richard Sennett, *The Craftsman* (New Haven: Yale University Press, 2008), 9.

space" where the *master*, who was the authority in the process and *apprentice* or *journeyman,* confronted and solved the issues face to face and in real-time.[113] Throughout the narrative of pre-industrial production, Sennet revealed the *autonomy* and *originality* of the craft and the *collaborative*, *hierarchical* structure of the atelier, and thus described craftsmanship as a way of making. As a result, Sennet provided a broad understanding of the nature of production in the Middle Ages until its defeat to the way of machine manufacturing.

> In Alberti's theory, a building is the identical copy of the architect's design; with Alberti's separation in principle between design and making came the modern definition of the architect as an author, in the humanistic sense of the term.[114]

Figure 4.3. 3D Printed Chair, Gilles Retsin, Manuel Jimenez Garcia, Bartlett UCL, 2015. Retrieved from http://fourthdoor.co.uk/. Accessed 6 Jan. 2022.

In addition, the division of craftsmanship into the design and making in the Late Renaissance, and thus a clear hierarchical distinction between architect and builder, gained importance at this point. Architectural historian and critic Mario Carpo has pointed to Leon Battista Alberti, describing the separation of design and construction as inventing the modern architect as "a thinker and a maker of *drawings*" rather than

[113] Ibid, 54.
[114] Mario Carpo, *The Alphabet and the Algorithm* (Cambridge, Massachusetts; London, England: The MIT Press, 2011), x preface.

"a maker of *buildings*" like a craftsman.[115] With this distinction, architectural design has turned into an intellectual act performing "notational art" by separating the profession form the manual work of production.[116]

In the last decades, the architectural *design* in which geometrical and constructional limits were eliminated with the inclusion of digital in architectural practice in the 1990s has narrowed the gap with *making* as a result of the "technical continuity" achieved between computer-aided design (CAD) and computer-aided manufacturing (CAM).[117] In this period, which is considered as the rebirth of the idea of craftsmanship and the potential to return to the workshop and atelier logic, the new digital production process narrows the gap between designing and making, offering a participatory, interactive and collaborative environment. Hand/mind integration also provides non-standard and non-linear relationships throughout the design process, and in parallel, the visual expression and language of architecture have also been transformed.

Figure 4.4. Digital and Making Integration. Tecla House, Italy, Mario Cucinella Architects, 2021. Retrieved from https://www.archdaily.com/. Accessed 9 Jan. 2022.

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[115] Mario Carpo, "Digital Darwinism: Mass Collaboration, Form-Finding, and the Dissolution of Authorship," *Log* 26 (2012): 98, https://www.jstor.org/stable/41765764.
[116] Ibid.
[117] Mario Carpo, "The Craftsman and the Curator," *Perspecta* 44 (2011): 87, https://www.jstor.org/stable/41662949.

The residential project Tecla, one of the latest 1-1 realization, was designed and fabricated with a computer-aided process. The production of the house, which was 3D printed with the rapid prototyping technique, designed by Mario Cucinella Architects (MCA), was completed by the Italian manufacturing specialist WASP. The Tecla house was made from a local soil and water mix and was built as the first eco-sustainable house model. The fabrication of the structure consists of a rotating arm from a central point and adding/processing the material layer by layer.[118] While the language of this layered fabrication is reflected in the wall texture of the project, the rotational movement of the machine has also been reflected in the form of the building. Instead of a standard combination of architectural elements and tectonics with the separate relations of columns, walls, and floors, a unique language has been achieved that unites the whole system.

Figure 4.5. Digital Grotesque II, Michael Hansmeyer and Benjamin Dillenburger, 2017. Retrieved from https://www.designboom.com/. Accessed 6 Jan. 2022.

In addition, a new direction is evolving in computer-aided design that counts a new language of intelligence to the architectural practice. At the core of this approach lies the combination of architecture with artificial intelligence (AI/ML computing based on Big Data), one of the digital tools advanced with the development of computing technologies. The use of computer intelligence, which has the power and speed of

[118] Mario Cucinella Architects, “TECLA – Technology and Clay” https://www.mcarchitects.it/tecla-2 Accessed 28 Dec. 2021

processing billions of times more than a *human brain's ability*, as a tool in architectural practice has created a unique architectural language and visual expression hidden in the synergy between computer-aided architectural design and fabrication. It arises when non-human machine intelligence brings new toolkits such as new "point clouds," "volumetric units," and voxels (3-dimensional) to the architectural design process.[119] With such respect; Grotto II represents a language of artificial intelligence by notating and calculating 30-billion voxels to fabricate such monument.[120] The computation process of AI encompasses a series of trial-error experiments within the system which also indicates the real-time way of making between master and apprentice in the mode of craftmanship. Consequently, artificial intelligence manifests a complex, disjointed, broken, fragmented, discrete, and rough language with its creative interference in the mode of the way architects build and design.[121]

Figure 4.6. Design and Behavior Integration. H.O.R.T.U.S. XL Astaxanthin.g, EcoLogicStudio, 2019. Retrieved from https://www.ecologicstudio.com/. Accessed 9 Jan. 2022.

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[119] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 81.
[120] Dillenburger Benjamin, "Grotto – Benjamin Dillenburger," Benjamin Dillenburger, Numerical Material, accessed April 30, 2022, https://benjamin-dillenburger.com/grotto/.
[121] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017), 55.

Exploring the interdependence between digital in design and biology, nanotechnology, and genetics gives rise to another paradigm, another language of intelligence, living organisms. In the early stages of interaction with architectural practices, digital media and tools were widely used by architects to visualize the design idea. According to Kolarevic, the change in the understanding and perception of digital environments and tools started with the encouragement of their transformation from a "representational tool" to a "productive tool;" and it led to a new design language, "digital morphogenesis."[122] The constitution of an architectural form is quite different from the traditional processes achieved by sketching, as some CAD tools working with algorithms inherently require a series of mathematical data entries and calculations. In this design process, like the data entered by the designer, the digital design environment automatically generates a set of formal ideas and options that further enhance and transform the design.

Figure 4.7. Boolean Operator, Suzhou, China, Marc Fornes / THEVERYMANY, 2018. Retrieved from https://theverymany.com/. Accessed 6 Jan. 2022.

In biological studies of animal or plant embryos, the notion of morphogenesis refers to the "generation of tissue organization and shape" of a complex organism.[123] The term has become popular in many disciplines, including architecture, as a new

[122] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 17.
[123] Jonathan Bard, "Morphogenesis," *Scholarpedia*, Vol. 3, No. 6, (2008) doi:10.4249/scholarpedia.2422 Retrieved from Scholarpedia

understanding of generation systems that can be simulated. The production possibility of complex forms with computer-aided design initiated a break from the traditional network of relations and its static design norms. Nowadays, computer-aided architectural design operates in a more dynamic process, with more approachable complex geometric forms and easily integrated alternatives. In parallel, the grid system, its repetition, and symmetry brought by modern construction systems and later used with prefabricated industry have decreased with the mass-customization and fabrication techniques, in which the morphogenesis design language and its form provided. A significant example of integrating morphogenetic architectural design with environmental ecology and biology, H.O.R.T.U.S. XL Astaxanthin.g is designed and fabricated by London-based EcoLogicStudio using computer-based algorithmic design and 3D printing techniques. The inspiration for its algorithmic language and form comes from the development of coral organisms. This project comprises two interesting components: the polymer and the other is living organisms.

Another aspect of morphogenesis that attracts the attention of architects is its foundations in *behavior*. While morphogenesis design processes encourage the exploration of new areas in search of behavior, they also pave the way for the emergence of new possibilities regarding form, concept, and fabrication. From behavior to the concept, form to fabrication, the process of design turns into a synchronized and intertwined relation that transforms architecture into a self-organized system. As N. Dunn emphasized, "these aspects are of great interest to architects, since morphogenesis can assist the emergence of speculative designs that may explore possible scenarios in relation to the variety of parts."[124] Although the use of mathematical calculations to manage morphogenetic design in architecture and its algorithms was new in this period, the work of Antoni Gaudi is the first example of such an experiment.[125] Later, with the new generative digital processes,

[124] Nick Dunn, *Digital Fabrication in Architecture* (London: Laurence King Publishing, 2012), 68.
[125] The only similarity of Antoni Gaudi with this current condition is the way he discovered new scenarios by putting forward speculative works.

variable articulations of form came into the significance that actually stimulated the research of form as an adaptable detail. Consequently, these researches shifted the emphasis on "making of form" to the "finding of form."[126]

4.1.2 Post-Media: The Language of Old Media

> “The new avant-garde is no longer concerned with seeing or representing the world in new ways but rather with accessing and using in new ways previously accumulated media. In this respect new media is post-media or meta-media, as it uses old media as its primary material.”[127]

Lev Manovich's concept of post-media sheds light on the understanding of today's other aspects of architectural language. Rather than considering the emerging advancements and representing the age and the world in new ways, many architects, artists, and designers use accumulated design materials and elements, in other words, the *old media*. In this case, the former functional reasons for these design and architectural elements are, in general, ignored when they re-assembled. As if they were picked up from the debris, these elements are copied and pasted into the new design.

Figure 4.8. Design and Media Integration. Social Housing France, Antonini Darmon, 2016, Arcadia Cinema, France, Tracks Architects, 2020, Cappadocia Spa Hotel, Gökhan Avcioğlu, 2020, Sforza House, Taller de Arquitectura X, 2020 Retrieved

[126] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 17.
[127] Lev Manovich, "Avant-garde as Software: From "New Vision" to New Media." (Sep. 1999): 15 Accessed 6 Sept 2021. http://www. manovich. net/docs/avantgarde_as_software.doc

from https://www.archdaily.com/,https://www.dezeen.com/,https://www.gadarchitecture.com/,https://www.archdaily.com/. Accessed 9 Jan. 2022

Copy Paste: The Badass Architectural Copy Guide, published by The Why Factory, the research unit of Dutch architecture studio MVRDV, critically looked at today's copy-paste design language and considered it an obstacle to the development of architecture. On this subject, MVRDV's founding partner Winy Maas talks to Dezeen, a popular online architecture magazine, and says that architects and designers experience a condition around being original. V. Maas emphasizes that the unique aspect of architecture has suffered for some time, slowing down potential advancements in the discipline. In the book, it is seen that many contemporary architectures hold typological similarities with both current and previous precedents. In this context, architects are criticized for not being able to break away from history and not being open to current research, experiments and innovations.[128]

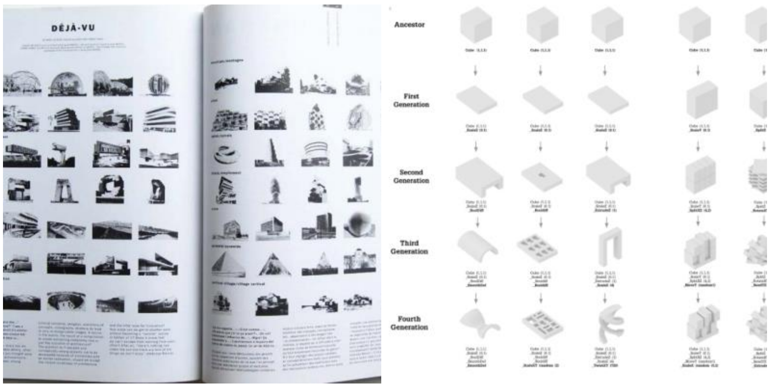

Figure 4.9. Originality Issue in Post-media. Retrieved from https://www.floornature.com/. Accessed 9 Jan. 2022.

On the other hand, in experimental digital surfaces such as KooZA/rch, another manifestation of the post-media language of architecture stands out, using a similar copy-paste action as a tool, but this time as creative, critical thinking, and criticism. In this digital platform, which is part of the Architectural Association School of Architecture of London, various works draw attention to critical thought, a situation,

[128] Winy Maas et al., *Copy Paste: The Badass Architectural Copy Guide* (Rotterdam: nai010 Publishers, 2017).

or potential that pushes the limits of architecture, with mostly a collage technique using existing architectural elements. For example, Aitana San José Aguilera, in the "Exodus" project, in order to keep the industrial chimneys, which are losing their importance today, as a cultural value, re-functionalized as a design element.[129] In yet another work called "Wheat Belt," Renan Teuman reproduces the truss and structural elements and reuses them as a connecting element.[130]

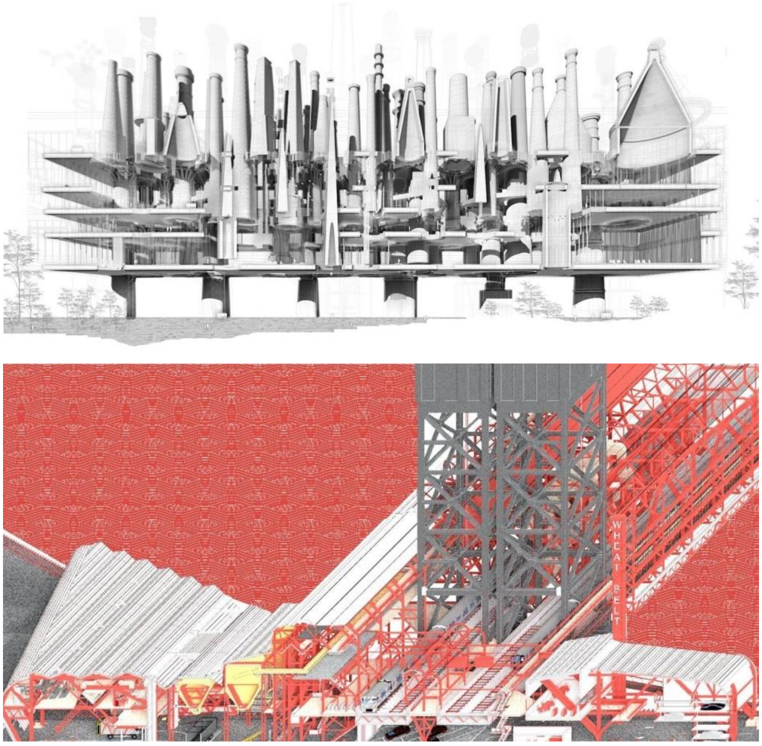

Figure 4.10. Critical Manifestation of the Post-Media Language. Exodus, Aitana San José, 2021 (Top) Wheat Belt, Renan Teuman, 2021 (Bottom). Retrieved from https://www.koozarch.com/,https://www.koozarch.com/. Accessed 9 Jan. 2022.

Another dimension of this discussion covers the transformation of collage from a physical cut-and-paste action with scissors to a photoshop action made with merging and morphing techniques today. In the post-digital age, it is debated whether such

[129] Aitana San José Aguilera, "Exodus" Heritage | Preservation | Retrofit | Urban Regeneration, interview by KooZA/rch, May 27, 2021, https://www.koozarch.com/interviews/exodus/.
[130] Renan Teuman, Wheat Belt, interview by KooZA/rch, October 25, 2021, https://www.koozarch.com/interviews/wheat-belt/.

works, which try to act as collages rather than generating a new "digital collage," are romantic/nostalgic attitudes or absurd contradictions.[131] Overall, the use of old media as a design language interestingly exists today both in digital media and in the built environment with two opposite perspectives.

4.2 New Limits of Space in Architecture

The invention of the telegraph signifies the separation of information from the papyrus paper and stone slab with which it has been associated for centuries, and similarly, from the messenger that also means a detachment from nature, roads, and travel. A similar alteration in the transport of information has been experienced today with the invention of the computer. Material-based production processes have begun to diminish with the spread of its virtual alternatives. Just like 50 years ago, a writer needed paper to practice, and an architect needed a ruler and sketch paper to draw; today, all this production process has been detached from all these materials.[132] At this point, it is questionable whether the architecture as an embodiment, which is both the receiver (from the architect) and the sender (to the subject) in information transfer, is weakened by these virtual spaces. There are indeed many contradictory opinions on this subject, as there are many debates. However, the common agreement is that architects should be very well aware of these new dimensions that threaten their foundations.

In such an environment, the advancing components of technological products are no longer based on their traditional organizations, geometric and mechanical assembling schemes, but more abstract, virtual connections and network links. French professor of the History of Architecture and Technology Antoine Picon, in

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[131] Bilge Bal and Bahar Avanoğlu, "Mario Carpo Ile Söyleşinin Ardından: İkinci Dijital Çağda Mimarın Eğitimi," *Mimarlık Dergisi* 405 (January 2019): 23, http://www.mo.org.tr/mimarlikDergisiDocs/pdf/MIMARLIK405.pdf

[132] Marshall McLuhan, *Understanding Media: The Extension of Man* (Cambridge, Massachusetts; London, England: The MIT Press, 1994), 89-90.

his book *Digital Culture in Architecture: An Introduction for the Design Professions*, evaluates the alteration between the two making in pre-and post-digital design as follows:

> Nothing was more admirable than the systemic or synergetic arrangement of elements that characterized a Gothic cathedral or a bicycle. Computers and more general electronic equipments are no longer designed according to these principles. They appear as layered assemblages of hardware and software. In these stack-like assemblages, systemic or synergetic organization is replaced by a different and in some ways looser type of relation based on interfacing. Interfacing has more to do with problems of code-writing and translation from one code to another than with traditional structural design.[133]

These two different conditions are unavoidably similar to people's perceptions of the condition of the city today. The virtual space that users are experiencing through digital and the physically shared space they dwell in prove the contrast and confusion, even for the designers and architects. In the end, there seem to be two worlds, virtual and physical, where architecture has been influenced since the digital revolution.

In that sense, in his influential text *Tarzans in the Media Forest*, Toyo Ito argues on behalf of the architects of the virtual and ordinary body of the subject. He writes, "we people of the modern age are provided with two types of body to match these two types of nature: the real body which is linked with the real world by fluids inside it, and a virtual body linked with the world by the flow of electrons."[134] His design, Sendai Mediatheque and its body, which is heavily material with its colossal steel plates and its fluid translucent features like the flows of electrons, can be read as a metaphorical transposition of having the two bodies.

Our perception of space today comprises two: real space that is tangible and virtual space that extends to the realms of seamless mediums. First and foremost, these

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[133] Antoine Picon, *Digital Culture in Architecture: An Introduction for the Design Professions*. (Basel: Birkhäuser, 2010), 120.
[134] Toyo Ito, *Architecture Words 8: Tarzans in the Media Forest* (London: AA Publications, 2010): 119-120.

virtual spaces are indeed virtual mediums or in other words, media. From Walter Benjamin's *Art in the Age of Mechanical Reproduction* (1936) and Marshall McLuhan's *Understanding Media* (1964) to Lev Manovich's *The Language of New Media* (2001), and to the most recent ones, the theory of medium and media is debated and conceptualized to understand the current conditions of information. This new dimension, in fact, goes back to the early days of media theories. McLuhan's interpretations of the medium, which were not even as advanced as today's, are significant in understanding today's information society and digitalization. In the light of McLuhan's work, four distinct facets of the mediums come to the fore. One is that the mediums are not disinterested, so they have both "psychic and social consequences, without regard to their content" secondly, mediums are "extensions of the men's and women's senses," and thirdly, "each medium is in constant interplay with other media." Lastly, mediums "manipulate our perception of the space and time."[135] Today, in the transition from the traditional medium to the digital, it is seen that new computer-related mediums are intensely in this field of influence. As L. Manovich observed, these new mediums can be exemplified as computer games, websites, blogs, mobile interfaces, interactive environments, and virtual reality.

4.2.1 Metaspace: Intersections of Architecture with New Mediums

Meta, as a prefix, comes from the Greek word *meta*, meaning "after, behind; among, between." Additionally, its second meaning, "changed, altered," and thirdly, "higher, beyond," are closer to the meaning used these days to explain the altered conditions. In the modern sense, meta has another meaning that causes misinterpretation and also affects the use of the word metaspace. This misinterpretation is "transcending," which comes from the meaning of metaphysics as "science of that which transcends

[135] Miani, Mattia. "Mcluhan And the Theory of Communication," *Noemalab.eu*, https://noemalab.eu/org/sections/ideas/ideas_articles/pdf/miani2.pdf Accessed 8 Nov. 2022.

the physical."[136] Due to this definition, metaspace means "a space transcending ordinary physical space" and defines a digital extension of the physical space. When these digital extensions are directly related to communication over electronic devices, it is called "cyberspace."

Cyberspaces constitute a virtual medium that allows a new way of human-human interaction through a computer or mobile devices. In these spaces where sensory and auditory senses are predominantly involved rather than traditional tactile communication, software technologies are used to increase the participant's experience. "NFTism," a virtual gallery displayed at Art Basel Miami Beach, was designed by Zaha Hadid Architects (ZHA) as cyberspace for NFT artists and their works. NFTism was designed and incorporated with the metaverse, which is briefly explained by ZHA as "an online environment, coupling spatial and interaction experiences of cyberspaces with supporting social, community forming and economic infrastructure."[137] Apart from the digital architectural elements, the designing process includes a series of cloud, network, visualization, and video-game technologies to build three-dimensional, interactive, and online spaces.

Figure 4.11. Virtual Gallery as an Altered Metaspace. NFTism, Metaverse, Zaha Hadid Architects, 2021. Retrieved from https://www.zaha-hadid.com/. Accessed 9 Jan. 2022.

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[136] "Definition of Meta-". *Online Etymology Dictionary,* https://www.etymonline.com/word/meta-. Accessed 2 Oct 2021

[137] "'NFTism' at Art Basel Miami Beach – Zaha Hadid Architects," Zaha Hadid Architects, December 2021, https://www.zaha-hadid.com/2021/12/01/nftism-at-art-basel-miami-beach/.

Video games are another metaspace that stands out in its relation to architectural design. While architecture was a resource that fed the video game space, its construction, and environment at the beginning of the industry, the one-sided relationship has turned into a mutually beneficial relationship between architecture and games. The gap between the two disciplines narrowed since game design proceeds through the same mechanics and software as architectural design. However, at this point, the difference between the subject of architecture and the subject of the video game comes to the fore. Unlike architecture, video game venues are environments in which the player can be involved at any time. As for architecture, the design is not enough for it to be experienced; its physical construction has to be accomplished for a proper architectural involvement of the user.

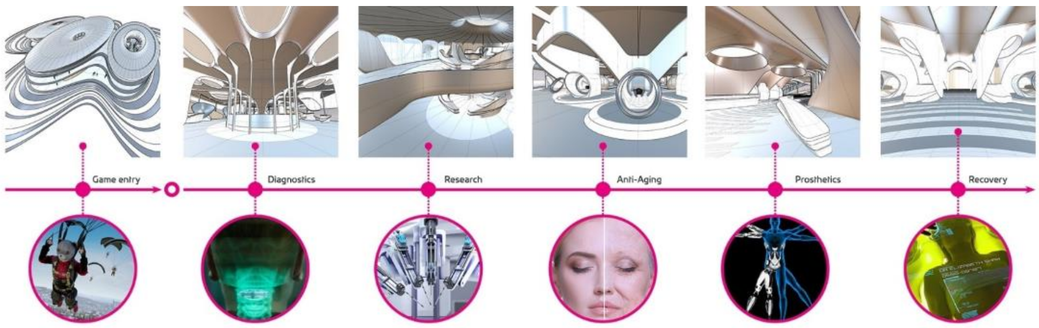

Figure 4.12. User Experience Design in Video Games. Medical Center for PUBG Mobile, Zaha Hadid Architects, 2022. Retrieved from https://www.zaha-hadid.com/. Accessed 3 May 2022

In video game spaces, architects also achieve a domain to design typologies that they haven't dealt with in real-life. For instance, Medical Centre for e-sport PUBG Mobile was chosen by Zaha Hadid Architects to deal with a hospital typology. Even in such a virtual nature, the ideas of the design consisted of well-being, engagement with nature, and panoramic views of the environment. In the game, every player starts with a parachute landing to strategic locations/building blocks that include essential assets for the player to survive as the last standing. Such user engagement provided a view from the top of the buildings, which is usually rare to experience in daily life.

Thus, the top view also became another significant element/façade for architects to design.[138]

On the other hand, the space design that generally attaches more importance to the functionality, aesthetics, and perception of space tackles another point, the strategical aspects. Vulnerability of being in a closed area, tactical standing locations and viewpoints, and various vantage points took part in the design process. In addition, trying to adapt to the game design constraints with the limited amount of polycounts and performance restrictions became another case for architects to consider.[139]

Considering that architecture is a functional living space, designing an architectural space and a video game space cannot be regarded as the same activity. However, both architecture and video game design has similar concerns by meeting at the point of 'experience of the subject' and supporting each other in developing it. In video game design, architecture emerges as an element that makes the scenes and game worlds realistic. By using 3D representations of tangible architectural assets and historical buildings, developers try to reach a more lifelike experience for players. Some of these representations' accuracy attracts the attentions of archaeologists and historians.

Assassin’s Creed, as one of those games that take place in post-classical history, portrays a very dense reconstructed environment and

> building materials and styles are period accurate; city layouts and landscapes conform to what is known about their original geography, other material culture mostly adheres to the style and technology of the day, people tend to be dressed and act appropriately, and scenes of daily life fit within scholarly expectations.[140]

[138] “PUBG MOBILE X Zaha Hadid Architects,” Zaha Hadid Architects, Accessed May 5, 2022, https://www.zaha-hadid.com/2022/04/06/pubg-mobile-x-zaha-hadid-architects-behind-the-scenes/.
[139] Notes from, PUBG MOBILE, “PUBG MOBILE x Zaha Hadid Architects | Behind The Scenes,” *Youtube*, Uploaded 5 Apr. 2022, https://www.youtube.com/watch?v=UVerq5DSdKU Accessed 25 Apr. 2022
[140] Aris Politopoulos et al., “‘History Is Our Playground’: Action and Authenticity in Assassin's Creed: Odyssey,” *Advances in Archaeological Practice* Vol. 7, No. 3 (2019): 317–323.

Since video games seek for the players to walk around and explore the designed environment, there, architecture comes to the fore with its potential contribution. These games usually have a vast open-world that leads players to explore every designed part of the game. Such an exploration process in video games like Assassin's Creed makes history and architecture a playground.

Figure 4.13. Game Space as an Altered Space. Assassin's Creed: Odyssey. Retrieved from *Let's Visit the Parthenon - History Tour in AC: Odyssey Discovery Mode* https://www.youtube.com/. Accessed 9 Jan. 2022.

On the other, another metaspace, social media, also known as social networking like Instagram and Twitter, has come forward as a new medium that enhances the communication of the masses. Apart from their social, political, and economic aspects, these social mediums build communities that integrate architects, clients, and those interested in architecture over a mobile device. Social media are indeed used for an information flow and interchange, as in when traditional media like magazines and videos were used for the same motive. However, initiatives like Plan Attack are cases where new media's creative engagement and interactive feedback features arise. Integration of architecture and social media Instagram was established by a graduate architect Matthew North with its project Plan Attack. As a host of Plan Attack, he shares stories of building plans with variable alternatives while asking for the participation of those interested by choosing one of the options he listed. The whole process continues with a series of collaborative design solutions for architectural floor plans. Consequently, followers are incorporated into the design process in an unprecedented way.

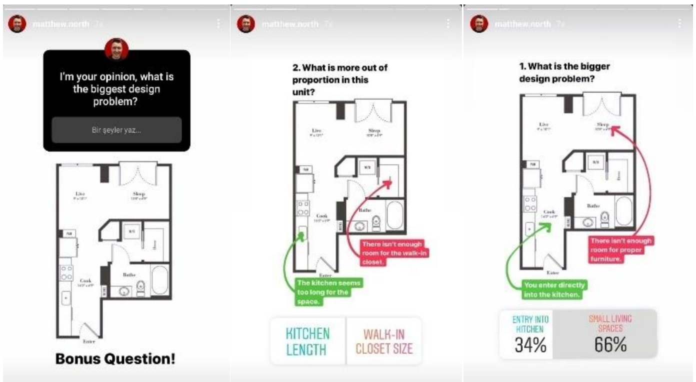

Figure 4.14. Participatory Design Process in Social Media Space. matthewnorth/Instagram. Retrieved from https://www.instagram.com/. Accessed 9 Jan. 2022.

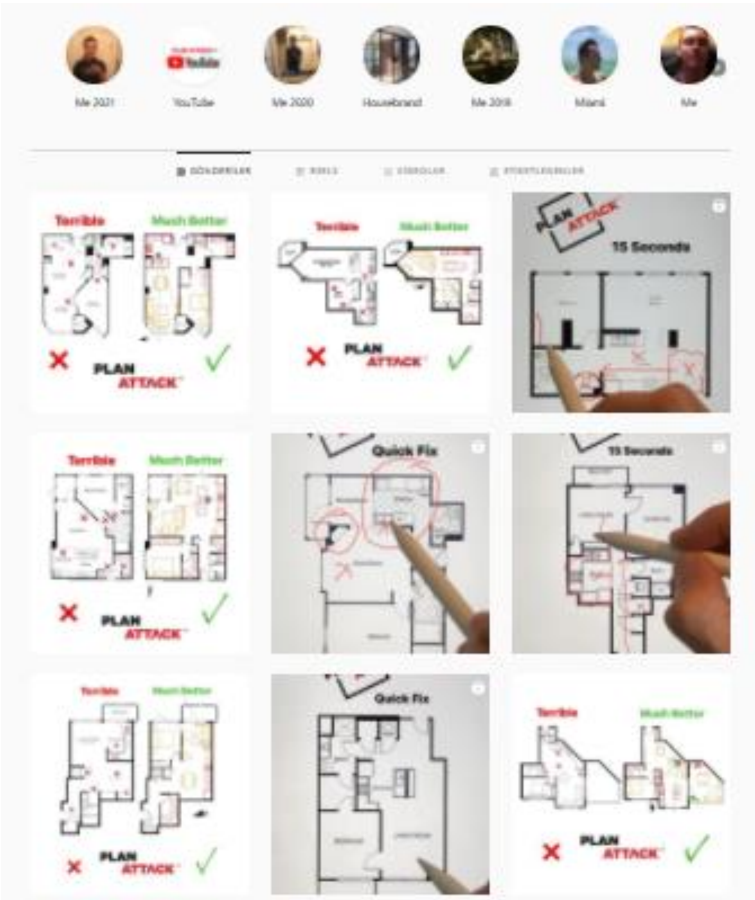

Figure 4.15. Educational Process in Social Media Space. matthewnorth/instagram Retrieved from https://www.instagram.com/. Accessed 9 Jan. 2022.

4.3 New Potentials in Mass Customization and Digital Fabrication

The concepts of digital fabrication and mass customization have been in the field of architecture since the digital turn; however, the new modifications, potentials, and techniques signal a second digital turn. A production system that is practiced today passes through a series of processes, including motion capture, racking system, deep learning by machine/artificial, and real-time fabrication by robotics. With the advancements in computation, robotics, and machine learning in the Fourth Industrial Revolution, the production process that is usually considered at the end of the design process has begun to merge and turn into a new generative design process. This section, which investigates the effect of transforming production in architecture, also touches upon the transformed production organization through the interface and software engagements brought about by digitalization.

4.3.1 Mass Customization: Non-Standard Mass Production

Modernism in architecture was influenced by the Fordist production brought by the industrial technology of the period and its easy and cheap manufacturability and became the simple, repetitive expression of rational geometries. However, the computer-controlled production that emerged with the digital age has made it possible to produce more complex and various systems with less cost.[141] In addition, CNC machines and 3d printers, which have been involved in architectural practice since the 1990s, facilitated the transfer from the computer screen to the physical world.[142] While all these developments have brought the concept of mass customization to architecture, they "opened up unprecedented opportunities for

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[141] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 84.
[142] Greg Lynn, "Continuing toward Extreme Mass Production," in *Mass Customization and Design Democratization* (New York: Routledge, 2019), 70.

architects to engage in complexity and variability informal articulation and the material realization of buildings."[143]

Beyond enabling digital representation and new design logic, these new technological developments have transformed the production method, which was previously based on molds or prototypes, into a *file-to-factory* process. File-to-factory is defined as a seamless relation of the design and fabrication process, which encompasses a "direct transfer of data from a 3D modeling software to a CNC (Computer Numerically Controlled) machine."[144] These new design and construction processes have become "more direct and more complex"[145] in that they are easy and quick to implement.

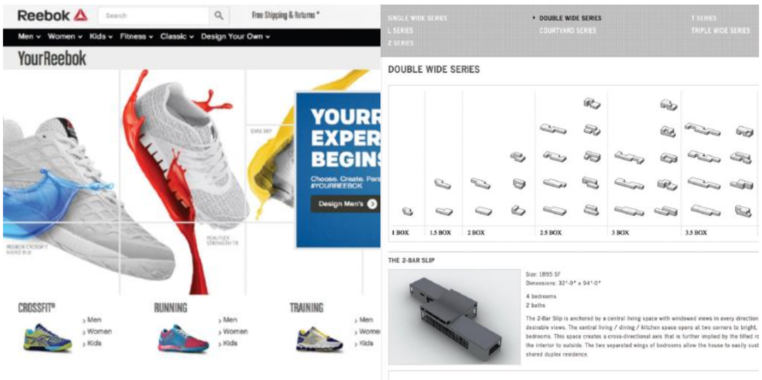

Figure 4.16. Designated by Customer and Mass-Produced Products (left), Customizable Housing with Pre-Defined Modules (right). Retrieved from book chapter *From Massive to Mass Customization and Design Democratization*, Branko Kolarevic and José Pinto Duarte.

The first architectural trials of mass customization were on housing projects that customers can customize via websites. In this process, customers were expected to

[143] Branko Kolarevic and José Pinto Duarte, "From Massive to Mass Customization and Design Democratization," in *Mass Customization and Design Democratization* (New York: Routledge, 2019), 2.
[144] Kas Oosterhuis et al., "File to Factory and Real-Time Behavior in ONL-Architecture," in *Fabrication: Examining the Digital Practice of Architecture, Proceedings of the 23rd Annual Conference of the Association for Computer Aided Design in Architecture*, 2004, 295.
[145] Branko Kolarevic and José Pinto Duarte, "From Massive to Mass Customization and Design Democratization," in *Mass Customization and Design Democratization* (New York: Routledge, 2019), 2.

choose the house design they liked and personalize it under certain limits. Again, similar approaches were also valid for other design professions so that today's customers can choose the materials and colors of products such as T-shirts and shoes and create their unique products.

On the other hand, Greg Lynn's Embryological House project reflects the impact of mass customization from a designer's point of view. This home project is a representation of how the design process, which includes procedural operations and tools, contributes to mass customization. Lynn tried to achieve formal and spatial variations by exceeding rigid limits by using the state-of-the-art technology of the period in the design of the project. The design, which consists of different combinations of 50,000 surfaces created using Maya's Script Editor, was then used for the Italian Pavilion using digital fabrication methods.[146]

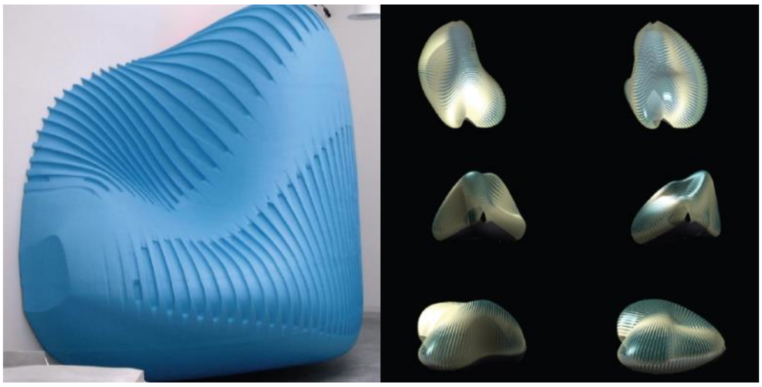

Figure 4.17. Embryological House and Digital Variations, Greg Lynn, 2001. Retrieved from book chapter *Continuing Toward Extreme Mass Production*, Greg Lynn.

In addition, these results are emerging because "the digital technologies are not used as a medium of conception but as a *medium of translation* in a process that takes as its input the geometry of the physical model."[147] In the case of standardization and the individual authorship of the architect as a designer, come to a discussion by

[146] Greg Lynn, "Continuing toward Extreme Mass Production," in *Mass Customization and Design Democratization* (New York: Routledge, 2019), 70-73.
[147] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 47.

indicating that the digital age provides participatory authorship, interactivity, a collaborative environment, and thereby a variability which is also similar to the pre-industrialized process of making. During the digital production process, this integration between architects, designers (with establishing participatory relations), and builders (with making on the surface or with robots and 3D printing) narrows the gap between the division of designer and maker.

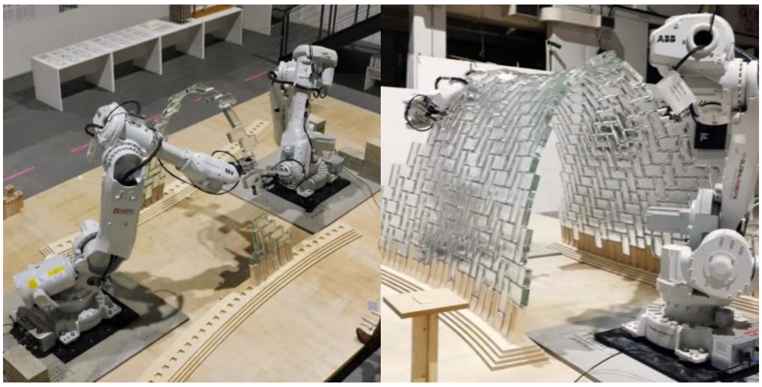

Figure 4.18. Automated Robotic Construction. The Glass Vault, SOM, c.r.e.A.te lab and Form Finding Lab, 2020. Retrieved from *Anatomy of Structure: The Future of Art & Architecture* https://www.youtube.com/, https://parametric-architecture.com/. Accessed 16 Jan 2020.

Within this context, the construction industry, especially computer-aided manufacturing (CAM) since the 90s, has developed rapidly in the last few years. The increasing existence of CAM has undermined the logic and economics of industrial prefabrication and its mass production, which has been going on for a while. In the meantime, computer-numeric control machines (CNC milling machines) took over the manufacturing and construction cycle, which is regarded as the "First Wave of Digital Fabrication"[148] in architecture. However, from task-specific computer-controlled production to more non-specific robotic production, which is coming to the forefront recently, has believed to be triggering the "Second Wave of Digital

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[148] Archim Menges, "Morphospaces of Robotic Fabrication," *Rob | Arch 2012* Springer, Vienna (2013): 28.

Fabrication"[149] and "Second Digital Turn," as Carpo pointed out.[150] This non-specific (non-standard) attribute,

> of the basic robotic hardware — that only becomes specific when equipped with a particular effector and tool – enables the design of new fabrication processes prior or in parallel to a specific project, and thus potentially challenges the conventional hierarchy and sequences still predominant in design and fabrication in today's architectural practice.[151]

4.3.2 Digital Fabrication: Computer-Aided Design and Manufacturing

Digital Modelling, Fabrication, and its tectonics, historically, go far back to the program developed for the French aerospace industry (Dassault Systems), called CATIA (Computer Aided Three-dimensional Interactive Application). By the end of the 20th century, this new software got a notice in industries such as automotive, shipbuilding, and consumer products. However, as a significant figure in theorizing digital architecture, Kolarevic, in his book *Architecture in the Digital Age*, pointed out that "the building industry among the last to change and adopt new technologies; CATIA had been in use for 20 years before it was discovered by Gehry's office."[152] With the intention of sustain effective design and construction process with complex, non-repetitive forms and curved surfaces of buildings, Frank Gehry and the tech unit began to explore the use of digital tectonics and its fabrication on computer-aided architectural designs. For a step taken in the early 1990s, it remained only a stimulus for developing the first digital tectonics due to insufficient building construction, prefabrication industry, and complex measurement systems.

Digital modeling and fabrication comprise the process of both design and production that integrates CAD and modeling with manufacturing and construction. Digitally

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[149] Ibid.
[150] Mario Carpo, *The Second Digital Turn: Design Beyond Intelligence*. (Cambridge, MA: The MIT Press, 2017).
[151] Archim Menges, "Morphospaces of Robotic Fabrication," *Rob | Arch 2012* Springer, Vienna (2013): 28-29.
[152] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 7.

fabrication of an object requires sets of 2D drawings and 3D modeling (including four models wireframe, surface, mesh, and solid) derived from CAD software. In his book *Digital Fabrication in Architecture*, Nick Dunn mentions four main principles of digital fabrication that are similar to the traditional process of modelmaking in architecture.

- *Cutting:* the most common, accessible digital fabrication technique used for the production of flat components derived from two-dimensional digital design data. A cutter head (laser-beam, plasma-arc, water-jet) and a sheet material are two primary components of this fabrication process that later can be combined with a particular pattern.
- *Subtraction:* is a subtractive fabrication that subtracts particular volumes from the existing solid material. A milling machine (CNC) and a three-dimensional volume are sufficient for this process to run while leaving behind more desired shapes with volumetric and accurate but fast results.
- *Addition:* is an additive fabrication that adds materials to build up the desired component in layers. A particular composite material is treated through the head of a fabrication machine that moves through a cycle of two-dimensional sheets.
- *Formation:* technique deforms or reshapes the whole into the desired shape rather than adding or subtracting material. For that, this process employs mechanical forces like heat and steam.

Currently, ongoing fabrication technologies are laser cutting, CNC milling machines (similarly, CNC saws and CNC joinery machines), rapid prototyping, 3D scanning, and robotics.[153]

One of the oldest digital fabrication techniques, laser cutting, was involved in production with CO2 lasers, since it was used to shape titanium sheets for aerospace

[153] Nick Dunn, *Digital Fabrication in Architecture* (London: Laurence King Publishing, 2012), 88-89.

applications around 1970s. At the same time, CO_2 lasers have become more common in cutting non-metallic products, such as in the textile industry. Recently, laser cutters have become widely popular, with corporate, industrial, and even personal uses ranging from schools to workplaces, from art to architecture. Regarding the materials used in laser cutting fabrication, materials that can fit the specific layer thickness, such as fabric, cardboard, plastic, wood, and metal, come to the fore. Additionally, another aspect that affects the plate thickness is the types of lasers that offer different methods such as melting, burning, or evaporation. Fabrication processes may also differ depending on the material and laser beam type, and the number of layers. When used with accurate techniques and settings, laser cutting offers a high-quality finish compared to traditional methods.[154]

In architecture, laser cutting spreads over a wide area, from small-scale use such as modelmaking to constructing semi-open spaces that rise to human scale. At this point, considering the two-dimensional end products of laser cutting, it is commonly preferred to be used in cutting detailed, curved, or patterned surfaces, which usually takes time to cut for complex structures. Again, considering the same reasons, for designs ascending to the third dimension should be transferred to two-dimensional information and has to be assembled after being produced in layered components. By reducing the cutting degree, laser cutting can also be used for processes such as marking, sorting, and even texturing to make assembling easier to facilitate.[155]

Andrew Kudless has used laser cutting as its mere fabrication technique to build a structural, free-standing surface, the Manifold Screen. By aiming for "the development of a material system with a high degree of integration between its design and performance."[156] Kudless developed a honeycomb system that can

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[154] Ibid., 90.
[155] Ibid., 91.
[156] "Manifold Screen - Matsys," Matsys, 2004. https://www.matsys.design/manifold-screen. Accessed 27 Nov. 2021

perform as a structural system. The project is developed with a RhinoScript to reshape the hexagonal geometry into an alignable, self-organizing internal system.

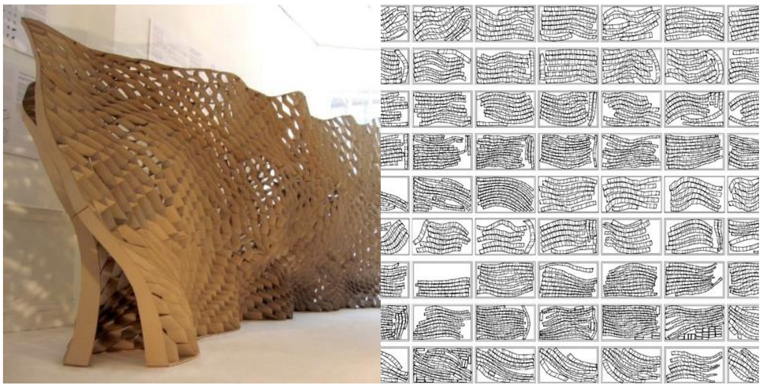

Figure 4.19. Laser Cutting Technique. Manifold Screen, Andrew Kudless, 2004 (Top), Laser cutting layout for the Manifold Screen (Bottom). Retrieved from https://www.matsys.design/, https://www.matsys.design/. Accessed 9 Jan. 2022.

The other digital fabrication technique used at the beginning of the digital turn is A Computer Numerical Control (CNC) Router, a computer-controlled machine that works with subtractive techniques. The CNC-based tools, including milling and routing processes, require a computer system to generate particular coded instructions that control the movements. These short computer scripts, also known as G-codes, tell the machine what to do. As the name suggests, CNC milling and routing work through two techniques. Both of these techniques work by *removing material* from the piece rather than adding it. However, the milling technique is applied for metals such as steel, titanium, and aluminum with a small cutting area, while the router is applied for non-metal materials such as wood, and plywood with a large cutting area.[157] On the other hand, one aspect to mention of this carving technique, is that it creates minimum waste in the production of non-standard pieces and thus offers both practical and economical solution.

The technique was used by Chris Bosse and PTW Architects for their pavilion design. Entry Paradise Pavilion is designed as a fair trade pavilion inspired by the *microscopic cell structure*. The project is portable and even fits in a bag with its

[157] Nick Dunn, *Digital Fabrication in Architecture* (London: Laurence King Publishing, 2012). 96.

component system. The pavilion, weighing only 17 kilograms, can be assembled in an hour and is fully reusable. Even though the whole structure looks as if it is solid, the high-technology nylon material and lighting usage manifests itself as elastic and soft that composes unique spaces. The workflow includes a series of biomorphic studies by using architecture software and then a process of transformation of a three-dimensional structure into an unrolled two-dimensional panel for CNC cutting.[158]

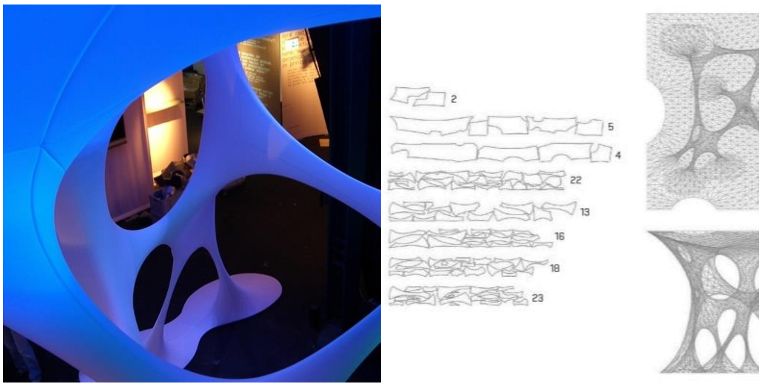

Figure 4.20. Entry Paradise Pavilion, Chris Bosse and PTW Architects, 2006. Retrieved from Lisa Iwamoto, *Digital Fabrications, Architectural and Material Techniques*, https://www.l-a-v-a.net/. Accessed 9 Jan. 2022.

Another digital fabrication technique that is recently started to be used for 1-1 realization of architectural projects is Rapid-prototyping. The technique, however, first emerged with the Stereolithography technique in the late 1980s and then became involved in many 3D printing-related industries, including architecture. Recently, it is the most common method in digital fabrication that works with the *additive* principle. Today, 3D printing machines, which are frequently used at homes and workplaces, are the equivalent of these digital fabrication systems. Rapid-prototyping consists of a laser that moves at an X and Y axis level and adds light-sensitive liquid polymer to each layer and a platform that slides up and down at Z-axis as each new layer is added. The meaning of *rapid* in this technique is related to the fact that the material begins to solidify immediately after it is added to the model.

[158] "Entry Paradise Pavilion, LAVA," www.l-a-v-a.net, Accessed 9 Jan 2022. https://www.l-a-v-a.net/projects/entry-paradise-pavilion/.

Since the final product caused by the plastic material builds some complications such as weeping, it must be revised for cleaning and correcting. In addition, another negative aspect of rapid-prototyping is the restraint of the machine itself that any end-product cannot exceed a particular size. For this reason, it is not widely used in architecture in the early applications of the architecture, except for small-scale works such as pavilions and model-making. However, any computer-aided project on a limited scale can be produced in one go with rapid prototyping, regardless of its complexity.[159]

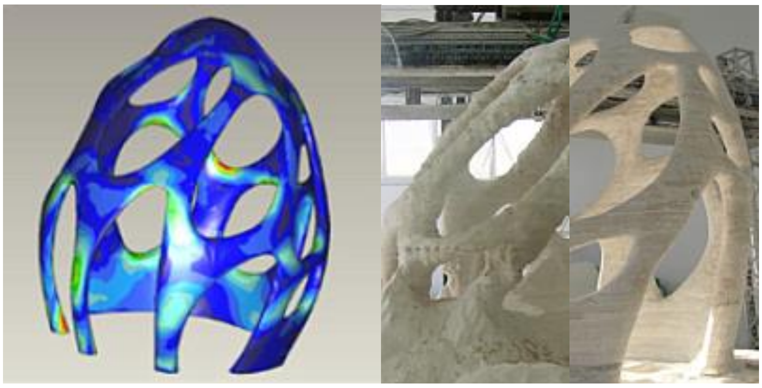

Figure 4.21. Rapid Prototyping Process from Modelling to Fabrication and Refinement. The Radiolaria Pavilion, Shiro Studio and D-Shape, 2008. Retrieved from https://blog.bellostes.com/. Accessed 9 Jan. 2022.

As a micro-architectural experiment, Radiolaria Pavilion is fabricated with the very first 3D mega printer by additive manufacturing company D-Shape and Shiro Studio collaboration. The main idea of this project was to demonstrate the capabilities of technology in construction by developing a large-scale structure that is monolithic, seamless, and free-form. The pavilion is made of:

> an artificial sand-stone material without steel reinforcement, the pavilion's design and execution had to be intrinsically resilient to several static stresses. Ernst Haeckels' studies on radiolarians and comparative anatomy was a source of inspiration; mineral and siliceous skeletons, through a gentle, evolutionary formation process share an affinity with the way that the mega-

[159] Nick Dunn, *Digital Fabrication in Architecture* (London: Laurence King Publishing, 2012), 102.

printer operates, through the gentle, slow deposition of mineral and siliceous material, layer after layer.[160]

Unlike the aforementioned processes and techniques that produce tangible end-products, 3D scanning can be defined as a production related to the digital environment. This technology plays a role in reading the already existing physical object and producing the information of this object as digital data. Some software can manipulate this digitally transmitted data, or exchange can be established and synthesized with existing CAD software. In architecture, when modeling on the screen with digital tools is complex, takes time, is not possible or not preferred, it enables spaces to be constructed and manipulated quickly, thus constituting a bridge with the digital.[161]

Technically, 3D scanning utilizes a laser to read or scan the targeted physical object. Depending on the object (surface, space, etc.) to be translated, the laser can be used through a digitizer or tripod-mounted box. The translation process can be done autonomously by setting up tripods and programming them or manually by projecting lasers onto surfaces like building façades.[162]

Figure 4.22. Physical to Digital Translation with 3D Scanning Technique. Inventory, oddviz. Retrieved from https://erdalinci.com/. Accessed 7 May 2022.

[160] Shiro Studio, "Radiolaria," http://www.shiro-studio.com/radiolaria.php Accessed 1 Dec. 2021.
[161] Nick Dunn, *Digital Fabrication in Architecture* (London: Laurence King Publishing, 2012), 108.
[162] Ibid., 109.

The art project "Inventory" by oddviz, which was founded by Erdal Inci, Çağrı Taşkın, and Serkan Kaplan, documented and preserved the characteristics of public spaces by using this 3D scanning technique.[163] Many other usages of 3D scanning and its possible future integrations are beyond limit. Today, the whole from physical-to-digital translation is also known as "reverse engineering."[164]

On the other hand, the 3D scanning technique has been used to develop the design process by transmitting the project that was worked physical model to digital. In that sense, The Louisiana pavilion was developed through physical modelmaking techniques by folding and exploring the curved structures and forms. Then using 3D scanning, the physical model was translated into digital information. With the reference of digital information, the fabrication process proceeds to the next step, which comprises molding, casting, and 'test-assembly' processes. The pavilion is also known for its self-sufficient architecture that its material behaves (absorbs and releases energy) according to the information of ambient temperature.[165,166]

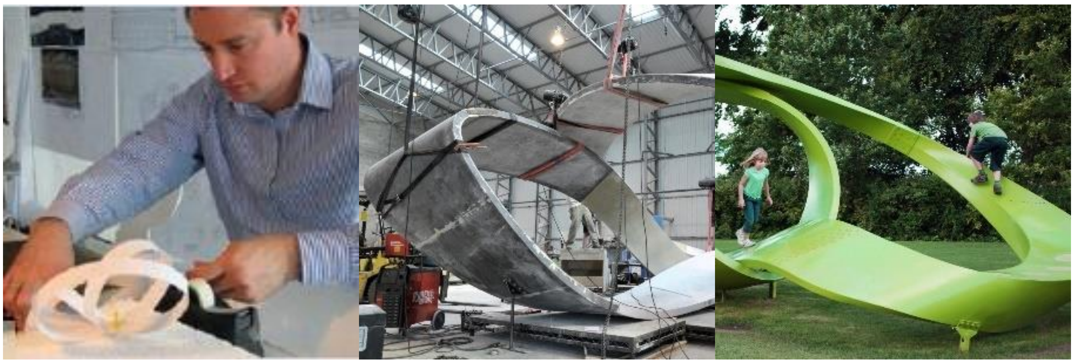

Figure 4.23. Translation from Physical Modelmaking to Digital. Louisiana Pavilion, Denmark, 3XN, 2009. Retrieved from https://gxn.3xn.com/. Accessed 9 Jan. 2022.

In recent decades, robotics has become an increasingly developing research area that influences architectural practice, interacting with machine learning, cyber-physical

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[163] "Inventory – Erdal Inci," Erdal Inci, Accessed 6 Jan 2022, https://erdalinci.com/oddviz/.
[164] Nick Dunn, *Digital Fabrication in Architecture* (London: Laurence King Publishing, 2012), 109.
[165] Ibid., 110.
[166] "Louisiana Pavilion, Can Architecture Learn from Nature?," GXN Innovation, Accessed 6 Jan 2022, https://gxn.3xn.com/project/louisiana-pavilion.

systems, and digital fabrication. As a multidisciplinary practice of engineering and computer science, robotics integrates engineering and mathematics fields with architecture by creating new directions in computer-aided design and fabrication. Since the 1970s, robotics has been used in architectural practice to operate constructions but left out of the process. The alteration of this condition was stimulated by the "articulated robots"[167] in studies of architects and researchers. Since robots are complex machines that can contain all the technologies mentioned above within themselves and are capable of more complicated applications, including technologies like lasers, scanners, and more, they can accomplish limitless applications. In addition, robots are not as limited as other technologies to their boundaries and their current location. As Dunn mentioned, its flexibility comes from:

> robot’s ability to work in a non-cubic space, self-referencing its position in relation to an object. In addition, the robot’s ‘hand’, also referred to as the ‘end effecter’, may incorporate an array of tools and be programmed to accomplish very specific, sophisticated actions.[168]

Figure 4.24. In-situ Robotic Fabrication of an Architectural Element (left), Non-Standard Production in Architectural Practice (right). Retrieved from https://ethz.ch/, https://www.instagram.com/. Accessed 11 Jan. 2022.

As a site-based fabrication practice, The Rock Print Pavilion is a project designed and constructed for the exhibition Hello, Robot, Winterthur in 2018, demonstrating a narrowed gap between humans and robots. The construction is performed by a

[167] Nick Dunn, *Digital Fabrication in Architecture* (London: Laurence King Publishing, 2012), 111.
[168] Ibid.

robot which is also known as an "in-situ fabricator,"[169] and lasts four weeks to build rock pillars. Researchers from Gramazio Kohler at ETH Zurich used the "jamming" technique with the twines in between each layer of loose, granular rock to keep rocks as pillars. As asserted by the research team, the pavilion demonstrates " the transformative power of digital construction processes by creating a pavilion out of a heap of loose aggregates tied up with twine by a robot."[170]

Figure 4.25. Robot & AI Museum, Melike Altınışık Architects (MAA), Seoul, 2023. Retrieved from https://www.melikealtinisik.com/. Accessed 1 May 2022.

Robots can perform advanced operations and movements that the 'robotic arm' can lift, hold, move, put, and even in between each action, and get any component to have procedures like cutting, adding, or subtracting. Moreover, through exploring the concepts like "motion capture, tracking systems"[171] and technologies like machine learning and robot programming, a collaboration between humans and robots can be achieved, as observed in the most recent studies. In that case, human actions provide the movement information to the CoBots to help throughout the process of construction. The advantage of such collaboration comes forward as

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[169] Isabelle Herold, "Rock Print Pavilion in Winterthur," ETH Zurich, September 28, 2018, https://ethz.ch/en/news-and-events/eth-news/news/2018/09/rock-print-pavilion-in-winterthur.html.
[170] Gramazio Kohler Research, "Gewerbemuseum - Hello, Robot, Winterthur, 2018," https://gramaziokohler.arch.ethz.ch/web/e/projekte/364.html Accessed 4 Dec. 2021.
[171] Dagmar Reinhardt et al., "CoBuilt 4.0: Investigating the Potential of Collaborative Robotics for Subject Matter Experts," *International Journal of Architectural Computing* 18, no. 4 (August 27, 2020): 353.

robots can "perform repetitive, dangerous or specified task sequence with optimized precision."[172]

For instance, The Robot & AI Museum by Melike Altınışık Architects, which is planned to be built in order to increase the robot interest and knowledge of the public in Korea, and is known to be an unprecedented museum in this context. The museum not only aims to exhibit robots but also aims to inhabit mobile robots that serve and construct. In this respect, "a sphere like non-directional, fluid and natural form" are designed as the metaphor and characteristics of the space of robots and visitors. The construction of the building will be done in a series of processes, including molding, assembling, welding, and polishing by a team of robots under the management of the BIM system. MAA office aimed to save effort, time, and money by leaving all operations and services to the robots in this project.

4.4 New Materiality in Architecture

> In effect, in all the branches of building, industry, as powerful as a natural force, invading like a river that rolls to its destiny, tends more and more to transform raw natural materials and to produce what are called “new materials.[173]

New design and construction approaches have developed with the integration of new production techniques and tools brought by digital and industrial developments into architecture. The introduction of these new technological innovations both motivated and accelerated experimental studies on materials, fabrication, and design processes in architecture. This cycle is catalyzed by the fact that each new architectural geometry/space leads to searching for new materials and vice versa. Most of the new material studies focus not only on the functional form (reinforced system, steel carcass) brought by material studies in modern architecture or the functional skin

[172] Ibid., 354.
[173] Le Corbusier, *Towards a New Architecture*, trans. John Goodman (1923; repr., Los Angeles, Calif: Getty Research Institute, 2007), 255.

(noise, light control) of post-modern architecture but also on the holistic and complex ways of designing and constructing the architectural space, as well as on the solutions of current social, economic and especially ecological problems.[174]

Living in such an age of material science, it is inevitable to hear of products such as recycled-plastic t-shirts, plastic-powered electronics, curvable willow glass, and self-healing concrete. New material innovations, aligning with the acceleration of development of new products over the past two decades, mark these times unprecedented compared to previous ones. The motivation behind these accelerated innovations could be considered the same as the factors that caused the changes that technology has undergone in the last few centuries. It could also be attributed to aero-space engineering and applications, which have rapidly developed in recent decades. For instance, "Memory Foam," used as a sports mat and instrument in daily life, was initially produced to resolve the physical complications that astronauts experienced during space flight. It could also be argued that the attitude taken against ecological and environmental destruction is a motivation. On this subject, Blaine Brownell, in his book *Transmaterial,* emphasizes that raw materials that were seen as cheap and endless in the industrial age, in the post-industrial age, turned into diminishing raw resources, polluter fossil fuels, and toxic industrial wastes, which makes it another interesting source of motivation that leads to advancements of new materials in today's society.[175] Although some of the events and phenomena mentioned above (wars, space and atomic periods, motivations of disciplines) have affected the development of new materials, it should not be forgotten that globalization and the demands of the capitalist system within the financial cycle also had an impact.

On the other hand, with digital and visualization technologies, the final image that initially emerges with the construction process has begun to appear digitally with software before its construction. Regarding this condition, architect and researcher

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[174] Maria Voyatzaki, “Computing Architectural Materiality: The Hyper-Natural Aspirations of the New Paradigm,” *International Journal of Architectural Computing* 7, no. 4 (December 2009): 561, https://doi.org/10.1260/1478-0771.7.4.555.
[175] Blaine Brownell, *Transmaterial* (New York: Princeton Architectural Press, 2006), 6-11.

Rivka Oxman conveys it as the transformation of production of buildings from the materialization of *paper-based drawings* to *digital information.*[176] Now, buildings are designed, fabricated, and assembled through digital. The ability to ensure a connection between design and concretization under control through these stages becomes an important feature that supports the system. Additionally, digital studies, which were also initially based on abstract algorithms at first and understanding the third dimension and its geometry, have passed into the experience of materials and investigation of the phenomenology of these spaces in the last two decades. Phenomenological research through digital experiences has led to an attempt to understand the experiences of variable materials and the emergence of unprecedented new material uses.

Figure 4.26. Brick vs Zero Carbon Emission Composable Brick, National Assembly Building, Bangladesh, Louis I. Kahn, 1982 (Left), Hy-Fi, New York, MoMA PS1's Young Architects Program Winner, 2014 (Right). Retrieved from https://elcafetindelas5/, https://arquitecturaviva.com/. Accessed 17 Jan 2022.

Applying new materials to architectural practice has not been as easy as industrial products or other small-scale applications. In addition, above all, testing new materials in large-scale architectural projects are risky and expensive. On the other hand, in an industry where the targeted life of a building is a minimum of 30 years, the outcome of the new material will be uncertain. Therefore, small-scale and

[176] Rivka Oxman, "Theory and Design in the First Digital Age," *Design Studies* 27, no. 3 (May 2006): 230, https://doi.org/10.1016/j.destud.2005.11.002.

temporary architectural projects such as the pavilion, exhibitions, cabins, shelters, and huts offer a freer surface to experience these new materials.[177]

The architectural sector and research-based offices trying to create architecture specific to digitalization and the new industrial era have a new palette of materials with variable degrees of "transparency, translucent, blurred, bright, folded, compressed or moveable that often 'melt' through light and data systems,"[178] as well as materials that manipulate appearance, the strength of structure or immaterial materials that create forms with light, heat, dampness, sound, vapor, and odor. Brownell has also categorized the latest trends that have come out with the new material palette as "ultraperforming," "multidimensional," "repurposed," "transformational," "recombinant," "intelligent," and "interfacial."[179]

The handling of the materiality of buildings within the contemporary industrial context and the current motivations towards new materials mainly has three focal points: Spatial Motivations that try to achieve new physical architectural space and organization, Ecological Motivation that aims to heal the built environment, and lastly Technological motivation that combines technological systems with materials.

4.4.1 New Materials with Spatial Motivation

Recombinant, multidimensional, and intelligent materials are composites consisting of complex combinations of multi-separate layers or fillings. Although there have

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[177] Thomas Schröpfer et al., *Material Design: Informing Architecture by Materiality* (Basel: Birkhäuser, 2012), 20.
[178] Maria Voyatzaki, "Computing Architectural Materiality: The Hyper-Natural Aspirations of the New Paradigm," *International Journal of Architectural Computing* 7, no. 4 (December 2009): 562–63, https://doi.org/10.1260/1478-0771.7.4.555.
[179] Blaine Brownell, *Transmaterial* (New York: Princeton Architectural Press, 2006), 6-11.

been many attempts to create these composites, they are "mainly used for limited applications and mostly for aesthetic purposes."[180]

As an illustration, a *recombinant* material (Panellite IGU) with LED-backlit was used in Burnsville Performing Arts Center with the intent to give definition to the entrance. Transparent columns at the entrance and throughout the façade were designed as a performative and aesthetic element using lighting and motion.

Figure 4.27. Burnsville Performing Arts Center, Ankeny Kell Architects, Burnsville, USA, 2009. Retrieved from https://i.pinimg.com/. Accessed 18 Jan 2022.

Recombinant materials are hybrids combined with two or more different materials that are better than the sum of those materials. These hybrids are developed with cheap and reusable components used as filler, or with a combination of components that achieves a harmonious multi-function, or with an achievement of a more valuable material than each component of this hybrid. In that sense, reinforced concrete is a precedent of such material combination.[181]

Considering the current composite material studies, the following materials are exemplary. Some of the recombinant materials can be:

[180] Osman Ataman, "Integrating Digital and Building Technologies: Towards a New Architectural Composite," *International Journal of Architectural Computing* 3, no. 2 (June 2005): 183, https://doi.org/10.1260/1478077054214442.
[181] Blaine Brownell, *Transmaterial* (New York: Princeton Architectural Press, 2006), 8.

- a combination of *cast acrylic* and *marble pebble* that uncovers the unity of granular stones to be used as a floor tile, tabletops, and counters;
- a hybrid product that combines *electricity* and *wood* through aluminum conductors that manifests the potentiality within the union of material and technology;
- a material produced by using the advantage of a sandwich wall system that consists of two layers: one that is structured like *a honeycomb system*, and the second is the *fiberglass* or *resin-based layer* that covers both faces. These panels can be both flat or curved and included in interior designs with their strong and rigid but lightweight composite structure;
- a combination of *glass* and *metallic interlayers* that provides more valuable features than any laminated glass material. These composites are interior and exterior glazing with features like solar radiation protection, acoustic performance, noise reduction, and other corrosions that make them durable components for glazed structures;
- a material made of *paper* and *wool* felt with a particular layer system that can also be used for acoustic and noise control. This hybrid material was used to construct a freestanding wall structure that can be reformed in any shape by curving and rearranging the positions.

On the other hand, with the new digital and technological developments, the structure imitating the functional-mechanical parts of the machine turns into an autonomous system structure with the abilities such as transforming, mutating, adapting, and changing. In addition, the relationship between the traditional building system imposed by the *functional form* and the *aesthetic skin*, which was later separated from the whole, has also transformed into a more complex structure that complements each other. At the same time, Professor of Architecture Maria Voyatzaki stated that this has been a new condition in handling building materials and attributes it to the "diminution of the importance of the distinction between load-bearing and non-load-bearing building materials."[182] Digital tools that enable the management of complexity beyond this traditional structure within the design-fabrication-assembly cycle also enable a reflection in *architectural space*. Regarding this condition, ETHER/I, a tessellated aluminum surface by dECOi Architects, demonstrates an architectural space defined by the design of the double skin material.[183]

Figure 4.28. ETHER/I, Mark Goulthorpe, dECOi Architects, Geneva, Switzerland, 1995. Retrieved from http://www.newitalianblood.com/. Accessed 15 Apr. 2022.

Flat surfaces such as walls and ceilings that define the *architectural space* are materials that became widespread in production even after research on the z-axis. Therefore, "augmented dimensionality" is a movement that continues to develop with today's technological developments and digital environments. Although *multidimensional* materials and applications seem complex enough and difficult to progress with their dimensional problematics, it is possible to develop new dimensions and understand their mechanics by viewing them from macro and micro scales.[184] One of the initial attempts of this condition was Mark Goldthorpe's *Aegis Hyposurface. This highly faceted surface* was driven by a mechanical instrument that included pistons, sensors, and actuators controlled over

[182] Maria Voyatzaki, “Computing Architectural Materiality: The Hyper-Natural Aspirations of the New Paradigm,” *International Journal of Architectural Computing* 7, no. 4 (December 2009): 561, https://doi.org/10.1260/1478-0771.7.4.555.
[183] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 235-236
[184] Blaine Brownell, *Transmaterial* (New York: Princeton Architectural Press, 2006), 8.

a computer system. The Aegis Hyposurface could deform and change its shape, light, and sound by responding in real-time according to the sensors.[185] Due to its responsive and adaptive dynamic skin and highly complex, electrical hybrid structure; this could be both "multidimensional" and "intelligent" composite that redefine the physical environment as well as the *wall* element.

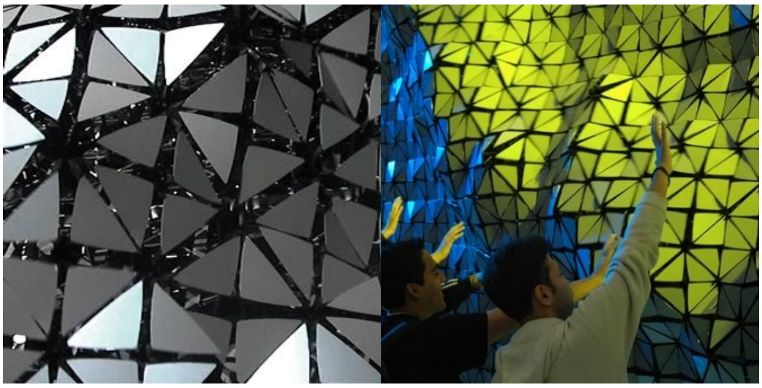

Figure 4.29. Aegis Hyposurface, Mark Goulthorpe, dECOi Architects, BIO International Convention in Boston, Massachusetts, 2007. Retrieved from https://www.musicworks.ca/. Accessed 15 Apr. 2022.

In addition to Aegis Hyposurface, some other multidimensional materials can be:

- a material designed with *corrugated anodizes aluminum sheets* that are *curvable* and *formable*. Changes in its thickness and depth of edges may develop different variations with unique designs. Some of these are 100% recyclable and not recommended for exterior, but rather for interior applications like displays, fixtures, column covers, etc;
- an *acoustic panel* for interiors to help the sound levels in crowded interiors. These panels can absorb and reduce the voice; thus, it is also used in the automotive industry to help noise problems in automotive design;
- a *curvilinear* ceiling panel that is used to transform the *top surface* into a unique pattern with dimension, form, and color. To enhance the experience, lighting can be installed either over or under, or middle of the system;

[185] Branko Kolarevic, *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 82-83

- an unordinary *plywood* material that is made of unique local wood and could be a *thin textile layer* used as a sculptural-wall component.

Figure 4.30. Winnipeg Skating Shelters, Patkau Architects, Canada, 2011. Retrieved from https://www.archdaily.com/. Accessed 16 Jan 2022.

Patkau Architects designed shelters by bending and deforming the thin layers of flexible plywood material. Each space is identified with an introverted skin and an opening formed with a slit. Skins are made with two layers of plywood that are cut according to the particular formation. Stress tests and technical experiments were made for bending points on a full-sized prototype during the design process. As a multidimensional attempt, Winnipeg Skating Shelters exemplifies the space-transforming property of the material, with the 2-dimensional layer gaining the third dimension. In addition, Archim Menges and ICD/ITKE of the Stuttgart University designed the ICD/ITKE Research Pavilion by Archim Menges and others from the Stuttgart University defined architectural space intending to integrate skin and structure in one mono-material, that no other constructional element needed. Thus, the project consisted of plywood strips that were robotically manufactured and connected with a bending behavior. The bending behavior of the material was not solely generating the form and structure but also establishing a set of "behavioral components that spatially mediate an intricate network of forces."[186]

[186] Moritz Fleischmann et al., “Material Behaviour: Embedding Physical Properties in Computational Design Processes,” *Architectural Design* 82, no. 2 (March 2012): 44–51, https://doi.org/10.1002/ad.1378.

Figure 4.31. Prada sponge wall, Los Angeles, USA, OMA, 2002. Application in Prada store (left), Fabrication process (right). Retrieved from https://aceprofileert.wordpress.com/. Accessed 18 Jan 2022.

On the other hand, for fashion brand Prada's clothing section, OMA created and used an "intelligent" material (Prada Foam) is made entirely from polyurethane that was cast to demonstrate a translucent, spongy like condition that contains dichotomies like solid and void, transparent and opaque, artificial and natural. The composite "somewhere between air and material"[187] brought about new questions to the boundaries of architectural space by enabling a new dimension to the walls.

Intelligent materials, aka. Smart materials are the main focus of today's material innovations, which are inspired by biological systems and derived from studies on microscopic scales. These materials can be active or passive and low or high tech. The intelligence of these products is not coming from their integration with a computational brain but rather from their innovative way of design. These may include some features like "pollution reduction, water purification, solar radiation control, natural ventilation, and power generation. An intelligent product may simply be a flexible or modular system that adds value throughout its life cycle."[188]

Intelligent materials can be multiplied by the following examples:

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[187] Christian Schittich, *Interior Surfaces and Materials: Aesthetics, Technology, Implementation* (Basel: Birkhäuser, 2008), 10.
[188] Blaine Brownell, *Transmaterial* (New York: Princeton Architectural Press, 2006), 9.

- a mineral clay roof tile that can be used within a particular temperature, region, and roof angle over 20 degrees and can self-clean;
- a decorative aluminum screen crafted with mathematical research, including research on the rhythmic, repetitional and sequential understanding of nature, to structurally stand;
- a polyester film that can be used with glass materials to manifest designed optical illusions. The illusion works when the viewer walks past the surface and looks at it from different angles. From some angles, it looks as if it is transparent. In others, it looks fully fogged, which provides a variable alternative.

4.4.2 Re-use and Bio-materials with Ecological Motivations

In the 18th century, the development of the capitalist economy and the Industrial Revolution increased immigration to cities and became the reason for rapid growth. In order to meet the increasing population and demands, the cities spread and scattered in an uncoordinated, structureless manner. In this process, many agricultural areas that could not adapt to the pace of the new economic system were lost; moreover, the acceleration of widespread use of transportation and production tools caused an increase in carbon footprint and climate change.[189] With the development of the Information Age, a series of reactions toward the constantly increasing ecological problems paved the way for the widespread attention to environmental ethics in society.[190] Approaches such as sustainability, green energy, biodiversity, and recycling stand out in this process, forming the basis of today's ecological attitude.

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[189] Hayriye Eylül Kaya and Arzu Taylan Susan, “Sürdürülebilir Bir Kentleşme Yaklaşımı Olarak, Ekolojik Planlama ve Eko-Kentler,” *Kent Araştırmaları Dergisi (Journal of Urban Studies)* 11, no. 30 (February 2020): 909, https://doi.org/10.31198/idealkent.53373.
[190] Hatice Ay, “Ekolojik Bir Toplum İnşa Etme: Toplumsal Ekoloji,” *Türk Yönetim ve Ekonomi Araştırmaları Dergisi* 1, no. 1 (February 2020): 12, https://doi.org/10.51243/SAKA-TJMER.

New materials and information technology are seen as a great opportunity to deal with nature again. First of all, today, being integrated with nature includes more complex approaches rooted in contemporary science rather than romantic approaches such as floral and art deco. At this point, new approaches, which are developing both in architecture and on an urban scale, overlap with fields such as bioengineering, morphogenesis, and non-anthropocentric.[191] These paradigms are commonly stimulated by human-centered thought system in a social and urban contexts built by industrialization. Therefore, the focus shifted to the intelligence and systems of non-human living organisms instead of man and his rational system. The trigger for this change has been the inevitable "interdependence" of digital and other disciplines (biology, architecture, genetics, engineering) since the 1990s.[192] In this respect, what emerged in the synthesis of digital and living organisms (mostly non-human) studies in the context of the architecture and the city also directs today's practice.

Figure 4.32. Algae Curtain, ecoLogicStudio with Urban Morphogenesis Lab (The Bartlett UCL), Synthetic Landscapes Lab (University of Innsbruck), UK, 2018. Retrieved from https://www.photosynthetica.co.uk/. Accessed 15 Apr. 2022.

Algae-powered, bio-smart cladding system Algae Curtain by ecoLogicStudio demonstrated a union between bio-digital and architectural material. The curtain was

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[191] Antonino Saggio, "Chapter 6: Other Challenges," in *Architecture in the Digital Age, Design and Manufacturing* (New York, London: Spon Press, Taylor & Francis, 2003), 324–25.
[192] Claudia Pasquero and Marco Poletto, "Bio-Digital Aesthetics as Value System of Post-Anthropocene Architecture," *International Journal of Architectural Computing* 18(2) (June 2020): 120, https://doi.org/10.1177/1478077120922941.

also installed at Dublin Castle during the week of the Climate Innovation Summit 2018, which aims to accelerate the "adoption of nature-based solutions to tackle the global climate crisis." The system was created as a lightweight and translucent skin that is able to capture CO2 from the atmosphere as much as 20 large trees. These skins, first and foremost, "functions as photobioreactor" and use daylight to sustain the "living micro-algae cultures." The directors of ecoLogicStudio Pasquero and Poletto assert the system of functioning in three layers: *wetware* (living microalgae cultures), *software* (digital management systems with sensors in real-time), and *hardware* (the habitable surface for cultivation of living cultures).[193]

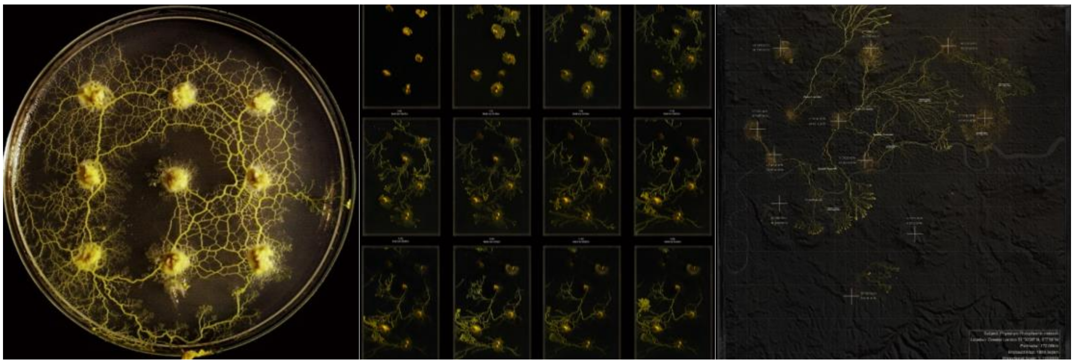

Figure 4.33. Physatopia, student project by Jiayi Tu and Qin Qing, Urban Morphogenesis Lab, The Bartlett UCL, UK, 2017. Retrieved from https://urbanmorphogenesislab.com/. Accessed 17 Apr. 2022.

Urban Morphogenesis Lab of Bartlett School of Architecture stands out with its research that utilizes biological intelligence in pursuit of a new mode of reasoning. These researches for both architectural and urban scales include a series of studies that:

- focuses on *collective (memory) intelligence* based on the growth of phycarum polycaphalum and the formation mechanism that can be used as a design tool. The project "Physatopia" later utilizes a digitally generated behavior model derived from the growing output of the organism.[194]

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[193] Ibid.
[194] "Urban Morphogenesis Lab - Physatopia," Urban Morphogenesis Lab, accessed April 28, 2022, https://urbanmorphogenesislab.com/physatopia.

- aims to explore the organization and fabrication technique of urban fabric with the help of *geomorphic and biotechnological intelligence*. The project focuses on the geography (Liwa Oasis in UAE) and the local resources (sand, cyanobacterial, chemicals) for their research. "Biocement" experiments with several formations and integrates them to spatial and urban scales.[195]

Figure 4.34. Biocement (Cynaobacteria), student project by Chunyi CHEN, Yilin ZHOU, Ying HU, Han LIU and Wenzhe YE, Urban Morphogenesis Lab, The Bartlett UCL, UK, 2014-2015. Retrieved from https://urbanmorphogenesislab.com/. Accessed 17 Apr. 2022.

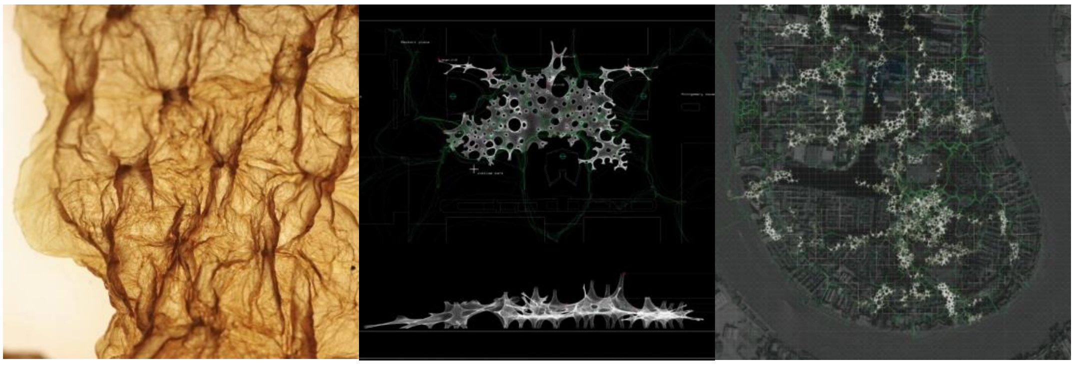

Figure 4.35. Microbialcellulose (Metabolizing Urban Waste), student project by Lipeng LI, Peng LI, Wenjuan HUANG and Xue XIAO, Urban Morphogenesis Lab, The Bartlett UCL, 2015-2016. Retrieved from https://urbanmorphogenesislab.com/. Accessed 17 Apr. 2022.

- problematizes the food waste and the air pollution caused by the burnt waste and suggests a new material for a solution, "microbialcellulose" (a symbiotic

[195] "Urban Morphogenesis Lab - BIOCEMENT [Cynaobacteria] 2014/2015," Urban Morphogenesis Lab, accessed April 28, 2022, https://urbanmorphogenesislab.com/biocement-20152016.

mix of bacteria, yeast, and other microorganisms). The biological material consumes food waste and turns it into an organic substance that is beneficial for energy reuse. The organism involves in the urban context as an energy infrastructure.[196]

In addition, repurposed materials, aka re-used, re-claimed, or re-cycled, a previously used material, or a product that has completed its function, came forward as another potential. In a way, it has a distinctive significance from other material trends in terms of its attitude toward the value of raw material, over-consumption, and waste flow in the new age. Today, it has many applications, from waste ship parts to the coating material to the re-functioning of art objects to tables, and it is continuing to develop.

Figure 4.36. Dapple Material as a Skin Element. Mehr.WERT.Pavillon, Karlsruher Institut für Technologie, 2hs Architekten, Germany, 2019. Retrieved from https://www.world-architects.com/. Accessed 17 Jan 2022.

Recycled dapple material was used as the skin of Mehr WERT Pavilion with an aim to prove both innovative and sensitive usage of waste resources. The project was showcased at the Federal Garden Show 2019 in Heilbronn, emphasizing recycled material. Similar to the recycled façade materials, re-purposed steel, which was used

[196] "Urban Morphogenesis Lab - MICROBIALCELLULOSE [Metabolizing Urban Waste] 2015/2016," Urban Morphogenesis Lab, accessed April 28, 2022, https://urbanmorphogenesislab.com/microbial-cellulose-20152016.

as a structural material, was taken from the Kneppers power plant that was disassembled at the same time.

Additional examples of re-purposed materials can be seen as:

- a finishing material for floors and may be used for cabinetry and other furniture. Kirei is also known as "sorghum-based architectural millwork material," which is a post-industrial recycled material and a renewable resource;[197]
- a material produced as a 100% polypropylene tube that looks like a beehive. Even though the material looks as if it is rigid, it is flexible, curvable, and formable in every sense. In addition, it is porous and translucent and may be used in interiors for sculpture purposes, panels, and functional objects;
- recycled postconsumer polyethylene panels are used in many areas as restroom partitions and store of furniture products;
- a 100% recycled rubber from children's boots can be used for wall coverings, floor mats, and similar areas.

4.4.3 Smart Materials with Technological Motivation

Recent developments in digital and production technology have brought along significant changes regarding the systematic formation and function of the material. While systems such as software, interface, and cloud, which were included in daily life with technological innovations, have been now integrated into the structure of new materials, new functional performances have been emerging with sensor/receptor, actuator, monitoring, and tracking systems at the same time.

Unlike their traditional forms, for instance, ultraperforming materials, also known as high-performance materials in engineering, are developed to achieve better strength, durability, functionality, lightness, and sustainability. These materials have evolved

[197] Blaine Brownell, *Transmaterial* (New York: Princeton Architectural Press, 2006), 8.

with constant testing of the limits, as new technology does today. The shattering of every limitation brings new thinking about the immediate environment, its design, and architecture. Especially in the built environment, the focus of material developments is the idea of reaching thinner, more porous, lighter, more transparent quantities, that is, "dematerialization" and even "ephemerality."[198]

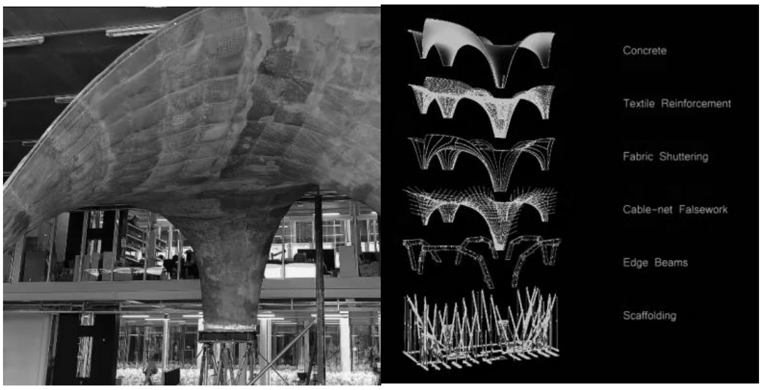

Figure 4.37. Ultra-thin Photovoltaic Concrete System on Roof Construction. ETH Zurich Researchers, 2017. Retrieved from https://www.youtube.com/. Accessed 15 Jan 2022.

As an ultraperforming material, Ductal concrete by LafargeHolcim integrated photovoltaic technology and material into a one-panel system. The photovoltaic concrete panel system consists of solar films called HeliaFilm, and thin, lightweight concrete layering. The shell was designed initially as a roof for an apartment called HiLo. The process included CAD and CAM testing of the structure's self-supporting and multi-layered aspects. Therefore, the thickness of the HiLo's concrete roof varied from 3cm to 12cm, from edges to supportive surfaces. Other ultraperforming materials can be examined as follows:

- a concrete material containing resources like mineral fibers, silica fume, superplasticizer, and many more to achieve lighter and durable wall panels, acoustic panels, and other construction systems that can also create thinner sections and higher structures;

[198] Ibid., 8.

- a translucent concrete material made by adding an array of polymers while casting concrete as a binder. By increasing or decreasing the polymer ratio, variations in transparency can be derived;
- a translucent silica aerogel that consists of 97% air and 3% silica. Since most of its composition consists of air, the gel material is light and *nanoporous* material with advantages in energy conservation and daylight transmittance as a light-transmitting insulation material on roofs and walls;
- a steel mesh chaise longue that aims to be nearly transparent. The membrane is made of welded stainless-steel mesh suitable for exterior applications.
- a wood material used for acoustic walls, roofs, and ceiling systems in theatres and mixed-use projects. These panels are made from wheat straw and recycled paper that come to the fore as both economic and time-saving construction systems;
- a 100% percent polyester of polyurethane material that has been developed can be rigid, rubber, or even gel forms as it is cast. The usage of cast resin is far beyond that; its applications encompass from wall panels and doors to tabletops and sinks;
- A fire-resistant glazing system manufactured from multi-layered safety glass with a transparent intumescent layer in between.

In the case of new materials' interactive, adaptive, and sensory applications, many materials and spaces use the recent industrial innovations (IoT, CPS, AI, ML) to establish links between people and spaces. In that case, MIT Media Lab developed an *interactive wall* that identifies the users and their feelings by using biological outputs. On the other hand, another study called "House_n" by MIT aims to build an immaterial link between home and places of work, learning, and recovering. On the other hand, "digital wallpaper," a currently developing prototype, constitutes another aspect of the motivation towards technology. The motivation behind this project is to prove that architects can also contribute to the industry with new technology. This new innovative material consists of separate flexible electronic circuit layers like sensors, display, networking, and solar cell layer that are pressed and defined together as one composite layer. It is believed that in the future, it will result in significant changes in architectural design, especially in the definition of the wall and its associated elements.[199]

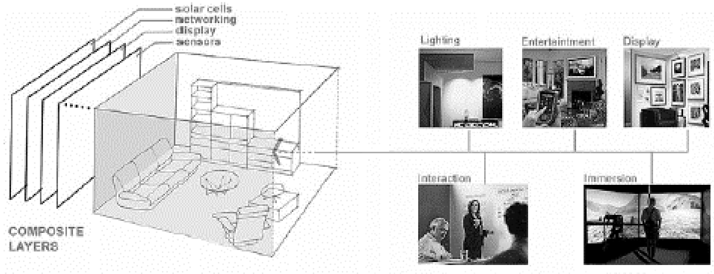

Figure 4.38. Digital Wallpaper Prototype. Retrieved from Osman Ataman, *Integrating Digital and Building Technologies: Towards a New Architectural Composite, 2005.*

In addition to multidimensional materials, there are also transformational materials that go through a bodily transfiguration yet are not kinetic that they may be autonomous or drowned by the users. Like smart materials, these are also developed with multiple features like solar control, waste reduction, illumination, and more that offer many functions, including more enhanced experiences. For instance, "The Give Back Curtain," designed by Kennedy & Violich Architecture, is a transformational fabric made of luminous phosphorus, also regarded as a techno-fabric that absorbs and reflects the light with the proto-luminescent pigments that are integrated into it.

In addition, the transformational materials can be as follows:

- a concrete material that transports light from one surface to other with the technique called 'Total Internal Reflection' that is also the same principle that makes fiber optics work. Its transformative feature comes from the shadows

[199] Osman Ataman, “Integrating Digital and Building Technologies: Towards a New Architectural Composite,” *International Journal of Architectural Computing* 3, no. 2 (June 2005): 181–89, https://doi.org/10.1260/1478077054214442.

or lights that fall on the materials' surface. It absorbs and responds with colors without any power or electricity;

- a responsive glass that acts according to the environmental conditions and transforms by curling, opening, and closing. The material is a lightweight, non-powered transparent material used for natural air movement and automated environmental control in buildings.

Figure 4.39. Fabric Woven with Proto-luminescent Pigments. The Give Back Curtain, Kennedy & Violich Architecture. Retrieved from Blaine Brownell, *Transmaterial*, 2006.

Figure 4.40. Laser Cutting Experiments with BL Special Material. Steven Holl Architects, 2006. Retrieved form https://www.albeflex.it/. Accessed 18 Jan 2022.

On the other hand, Interfacial materials have also emerged with the invention of the computer and interface in the digital age that aims to integrate two opposite things: physical and virtual. Investigating materials and their possible implementations with interface systems makes these materials unique within their own time. Products and materials fabricated through virtual instruments are also included in this section of trends. Additionally, interfacial materials are precious in terms of their involvement with the latest and newest technologies in the digital age, for it leads to unfamiliar fields in every advancement. BL Special, a laminated wood composite material that Steven Holl designed with Nick Gelpi, Alberto Martinuzzo, and Alessandro Orsini (albeflex), was developed for a laser cutter and other use rapid-prototyping techniques.

4.5 New Additions to Architectural Hardware

> "Within bitsphere communities, there will be subnetworks at a smaller scale still that of architecture. Increasingly, computers will meld seamlessly into the fabric of buildings and buildings themselves will become computers - the outcome of a long evolution."[200]

In 1996, at the dawn of digitalization, Mitchell asserted that as the Industrial Revolution transformed the pre-industrial buildings from *skeletons and enclosing elements* to progressively complicated *mechanical entities*, the inclusion of computers and automation will also transform the buildings into a never-ending complex construction with new advancement in technology.[201] In case of the pre-digital condition of the mechanical physiology of the building, systems like heating, ventilation, air conditioning (HVAC), electrical, safety systems, and more were embedded into the fabric of the buildings. With the inclusion of the computer, such systems have become automatic and even autonomous with the development of the industry.

The distinguishing principles of digitalization include the keywords "numerical representation, modularity, automation, variability, transcoding,"[202] digital, virtual, interactive, hypertextual, networked, simulated, demassification, and asynchrony,

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[200] William J Mitchell, *City of Bits: Space, Place and the Infobahn* (Cambridge, Massachusetts, London, England: Mit Press, 1996), 171.
[201] Ibid, 171.
[202] Lev Manovich, *The Language of New Media* (Cambridge: MIT Press, 2002).

and more could be included according to other studies.[203] The transformation in architectural hardware has started with the advancement of automation. The automation system, which was introduced in production with the Third Industrial Revolution, has developed while acquiring new technological additions with the new revolution experienced today. Since automation works with algorithmic software, no-human involvement is required. On the other hand, these extensions, associated communication systems, and CPSs remain complex systems that need cooperation with other disciplines.

Figure 4.41. Rendering software with minimum system requirements, a comparison between vray and twinmoion software. Retrieved from https://i.ytimg.com/. Accessed 28 Apr. 2022.

Today, even as an additional part of the computer system, hardware has turned into a design-accelerating attribute. Processor, graphic card, and RAM have become terms that every architect or architectural office should know due to the digital culture and developing industry. The hardware and computer selected in this process vary according to the type of work to be done and the software to be used; thus, the marketplace and service personnel may be insufficient in terms of necessary knowledge and mislead the customer.

[203] Martin Lister et al., *New Media: A Critical Introduction, 2nd Ed* (London; New York: Routledge, 2009).

Figure 4.42. Internet of Things and control over mobile devices. Retrieved from https://www.whsmarthome.com/. Accessed 28 Apr. 2022.

Today, especially in architecture, with the development of CPSs and the establishment of the relationship between each system with the invention of the IoT, industries have come to the fore under the name of "smart." These are known as 'Intelligent Buildings,' 'Building Management System (BMS),' 'Building Automation System (BAS),' and if it is integrated with housing, known as 'Home Automation,' 'Smart Building' that consists of the elements as actuators, hardware controllers and sensors in addition to the architectural elements. BASs have emerged with a principle that aims to improve the occupant's comfort. This building industry has developed and has become the indispensable essential element of sustainable buildings and green buildings that demonstrate controlled energy performance.[204]

Essentially, building automation is an automatic control center that manages heating, ventilation, air conditioning (HVAC), electrical, lighting, and shading systems in buildings. The new additions to its fundamental structure have become a crucial system of the modern industry with rising ecological concerns that improve energy efficiency, reduce operating and maintenance costs, archives building information, increase security, and enable remote interventions. At this point, if the BMS and the

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[204] Jim Sinopoli, *Smart Building Systems for Architects, Owners, and Builders* (Amsterdam: Butterworth-Heinemann, 2010), 5-6.

BAS are compared, while BMS is defined as the system that controls the fundamentals of the system, BAS is a system that includes everything else that is related to the electricity in the building.[205]

An extension of BASs is "Home Automation System (HAS)" also known as "Home Building Automation System (HBAS)" or "Digital Home." Unlike the complex BAS, HBASs are controlled by the residents from inside of the home through a control panel, monitor, or unit that typically includes a user interface with an Internet connection.[206] Applications of Home Automations systems varies with the particular combinations of HVAC, lighting control system, occupancy-aware control system, indoor positioning system appliance control system, home robots, security, detectors, elder and disabled systems including the devices like voice control (Amazon Alexa, Google), air control devices, smart home appliances (with built-in interface).

Figure 4.43. Ceiling Mounted Home Robot and Mobile Robot by Toyota Research Institute (TRI). Retrieved from https://assets.rbl.ms/, https://images.ctfassets.net/. Accessed 28 Apr. 2022

Recently, robots have been included in the context of domestic electronics to improve human capabilities in living spaces. As one of the leading teams in robotics, Toyota Research Institute (TRI) aims to enable robots to adapt to every human environment. Apart from the development of mobile robots, TRI advanced ceiling-

[205] M. Asadullah and A. Raza, "An Overview of Home Automation Systems," *2016 2nd International Conference on Robotics and Artificial Intelligence*, (2016): 27-31.
[206] Ibid.

mounted robots that can perform in narrow spaces.[207] Consequently, the integration of new technological hardware justified the predictions of Mitchell, who said, "computers will burst out of their boxes, walls will be wired, and the architectural works of the bitsphere will be fewer structures with chips than robots with foundations."[208]

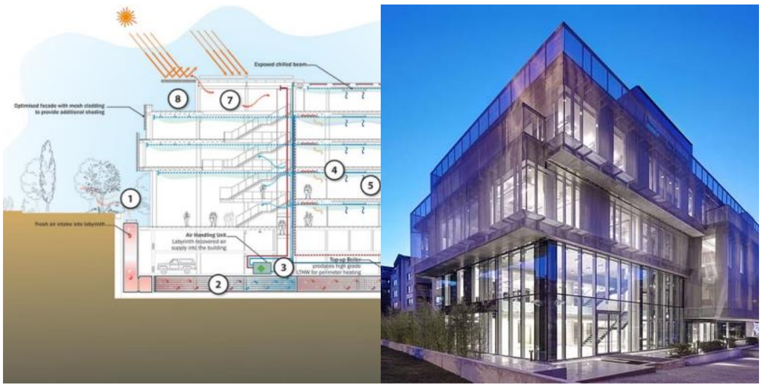

Figure 4.44. Türkiye Müteahhitler Birliği Merkez Binası, Avcı Architects, Ankara, Turkey, 2013. Retrieved from https://avciarchitects.com/. Accessed 4 May 2022.

On the other hand, one of the movements in architecture taken against the environmental problems caused by the Industrial Revolution over the years has been the *Green Building*, also known as the "zero-energy of near-zero-energy building"[209] The energy and environmental performance of buildings are certified with classification and evaluation systems such as LEED and BREEAM. "Mitigating environmental degradation through conservation, reduction of pollutants, and protection of water and natural resources and habitats,"[210] as well as improving social and economic health, are the main aims of the still-evolving concept of green buildings. In addition to these certification systems, green buildings can also incorporate specific targets according to urban policies and government regulations.

[207] "Robotics | TRI," Toyota Research Institute, n.d., https://www.tri.global/our-work/robotics/. Accessed 28 Apr. 2022

[208] William J Mitchell, *City of Bits: Space, Place and the Infobahn* (Cambridge, Massachusetts, London, England: Mit Press, 1996), 172.

[209] Frank Ching and Ian M Shapiro, *Green Building Illustrated* (Hoboken: Wiley, 2014), 6.

[210] Ibid., 7-9.

These policies vary from one country to other and differ according to regions, provinces, and districts and may include goals such as ecovillage and green cities.

One of Turkey's intelligent and sustainable architectural projects is the Turkish Contractors Association Headquarters, designed by Avcı Architects as a result of the competition. This project was completed with the participation of engineers from many different disciplines and received the LEED Platinum Certificate. In the design process, air circulation and temperature control were provided with a method defined as a "labyrinth system" and involved several active and passive systems with photovoltaic panels and hot water pipes.[211]

Like other automation systems, green buildings require the cooperation of architects, engineers, civil engineers, contractors, and clients. Therefore, the complexity of systems is reflected in the architectural drawing and modeling software, extensions, and tools, which helps the architects and engineers improve sustainability in projects and integrate and develop design simultaneously. One of the prominent tools, BIM and Green Building Information Modelling (Green BIM), allows users to get analyses such as conceptual energy analysis, solar and shadow analysis, and sustainable analysis by using the topographic, environmental, material, constructional information stored in the database.

[211] "TMB Merkez Binası," Avci Architects TR, Accessed 1 May 2022, https://avciarchitects.com/tr/proje/tmb-merkez-binasi/.

CHAPTER 5

CONCLUSION

Industrial and technological transformations have had multiple effects on architecture while transforming social and daily life. On the one hand, transformations from the Industrial Revolution to today's industrial technologies brought convenience and speed in production, economic growth, improvement in comfort and health conditions, ease of communication, and accessibility to broader geographies. At the same time, such an accelerated production has become the primary source of environmental pollution, energy consumption, widespread commodification, and surveillance problems. Understanding the current position required returning to the still-evolving post-industrial condition that came to the fore in the 1970s. The transition to the post-industrial period has taken place with the shift of information infrastructure from transportation to communication, from highway to cable, to the basic structure of today's society. Behind this change lies a new determinant called "computerization," in Lyotard's words, and the difference in how information is transmitted and obtained due to the changing status and legitimacy of knowledge. Thus, the resulting complexities and divisions are simultaneously reflected in disciplines, society, economy, and the built environment.

In the first instance, with the development of the Information (IT) and Communication Technologies (CT), new business areas have emerged under the novel tertiary sector of the economy, the service sector. New service-based job definitions such as project consultancy and management, real estate, investment, and expertise, as well as new requirements for working environment such as division of labor and organization, have aroused. The post-industrial process has led to the implementation of a series of national/regional de-industrialization and industrial re-localization policies in the form of re-adaptation, reduction, or even removal of the industry in the urban context. In addition to the cities' industrial, business, and recreation sections, functions/services such as health, education, transportation, and their positions have also gained importance.

However, with the increasing world population, demand, and consumption of goods, there has been an accelerating increase in industrial production rather than an expected decrease. Even heavy industry has continued to be an essential part of the economic growth strategies of countries such as China, Japan, and Korea. Meanwhile, the environmental threats caused by the industry have revealed the importance of waste control, restriction of plastic bag consumption, and other individual measures in daily life. Also, the development of digital/computer technologies has led primarily to the economy's financialization, resulting in an increase in financial value and a decrease in physical value. In addition to the capitalist system's marginalized labor, the finance-based economy has led to the precariousness of skilled/qualified and intellectual professions such as architects. In parallel, within the money-capital-money cycle, the conversion of architectural objects into capital has accelerated. The city and other settlement centers, which have become the focal point of financialization and globalization, have been transformed by capital owners into experimental areas with skyscrapers, oases, historical decorations, and neon lighting on the facade to add symbolic value to the capital cycle.

Since the 1990s, the internet, a real-time information transformation apparatus, has led to increased shared and collected data and has become an information bank with ample storage. Initially expensive and complex to access data due to limited shared data and storage capacities (compressed .zip and .rar files), it has become accessible and inexpensive as the accumulated data and storage (cloud servers, deep web) has expanded. This new source of knowledge provides the technical, scientific, experimental, and functional data necessary to solve contemporary problems while also enabling the development of artificial intelligence (AI), machine learning (ML), deep learning technologies, and quantum computers. Integrating big data and computation with nanotechnology, genetics, and biotechnology also triggers the development of robotic technology. Developments after the 2010s mark the Fourth Industrial Revolution, which provides an intelligent production system where machines and robots control, analyze and instruct each other independently of human interaction. As the core technology of the autonomous system, CPSs operate in a particular action cycle: first, certain information is collected by the sensors; IoT transfers specific data to the cloud or local servers simultaneously; synchronous feedback is received from these servers. One result of this new system is the upgrade of already existing "human-to-machine" and "machine-to-human" communication to a whole further "machine-to-machine" communication. In the meantime, the new limits of space brought about by digitalization were discovered when new experiences such as mixed reality (MR), virtual reality (VR), and augmented reality (AR) were created, paving the way for concepts such as the metaverse.

Architecture is, on the other open to both positive and negative impacts of digitalization and industrial technology. The influence of computers, computation, and digital tools (CATIA, Alias/Wavefront, CAD/CAM) in architecture manifested itself in the 1990s with the potential to create non-Euclidean, non-repetitive, and non-standard production systems as well as variable, complex, kinetic and dynamic forms. At that time, the integration of digital tools/software and computer-aided design depended on three primary uses: one as a means of presentation, digital representation of the idea; second to automate the process of drafting activities; and lastly, as a logic of design formation interdependent on the notation/algorithms superimposed on the design. In the end, the domination of curvilinear and fluid expression in the architectural language of the period was in general influenced by Calculus (the mathematics of continuity) and the NURBS Modelers and inspired by the creative potential of Deleuze and Guattari's folding. While this process allowed a new logic in the design process as parametric design, it has also led to the emergence of new styles and -isms in architecture, such as parametricism and blobism. In addition, the feasibility of highly complex surfaces and lines has enabled the realization of analogy with nature in architectural and urban experiments; for this reason, 'topological,' 'organic,' and 'rubber-sheet' characteristics have also been ascribed to the curvilinear architecture.

Today, unlike the early periods of the digital age, advanced cloud capacity/storage, network technologies, AI/ML, and computer processing power have triggered breakthroughs in digitalization and paved the way for the discussion of a second digital turn in architecture. First of all, within these developments, it is possible to (1) *realize a real-time integration between the **design** and **making** processes*. The distinction between architect and builder emerged after the Middle Ages, and the gap between design and construction widened afterward, has begun to narrow at the new digital threshold. While working on the raw state of design, architects can explore the constraints and possibilities of its construction through a series of simultaneous feedback mechanisms with new techniques (file-to-factory, trial-and-error, and in-situ fabrication). In that way, the design and formation process are merged and handled more holistically, thus improving the targeted 1-1 realization. Meanwhile, as it enables the "*design through making"* process and holds the potential of participatory, interactive, and hierarchical workshop logic, the results also mark the rebirth of craftsmanship performed by hand and mind.

Another impact of the transforming way of working, cheap and practical production and materialization has been the (2) *narrowing gap between **theory** and **practice***, thus *increasing **research-based** architectural practice*. Universities and research laboratories with the necessary resources and efficient facilities are observed to provide the potential to produce and participate in urban and architectural studies with novel technologies. In addition, many architecture students and academic staff, who have interdisciplinary experience with these opportunities, continue their studies through research-based architectural offices.

The driving force behind these practices lies in the architects' motivation to contribute to the industry with new technologies that (3) *offer solutions to **ecological**, **urban**, and **social problems*** besides the architectural concerns. These urban and architectural studies include variable approaches such as non-anthropogenic/non-human intelligence that responds to the environmental degradation caused by humanity and intelligent technologies embedded in the buildings' fabric. Thus, the inspiration for new projects may become living organisms that can regenerate, adapt, decompose and renew nature, or technological tools, components, and cables that can improve the performance of the built environment.

In addition to the current industrial technology, with the reflection of the changes mentioned earlier in architectural practice, it has become possible to create the adaptation of (4) *new languages by including the* ***intelligence of non-humans*** *such as artificial and living organisms* into the design and fabrication process. In the last decade, digital technologies and CAD/CAM practices have broken away from the limitations of the human mind. This shift's core is based on the transition from calculus to advanced computation driven by deep learning and machine learning (ML). Since these advanced machines can process billions of notations and calculations of a complex system more capable than the human mind, a new unknown and unfamiliar language is emerging within the architectural language. Rather than the calculation system familiar and common in architectural practice, different methods are being tested with new notation systems that utilize point clouds, volumetric units, and voxels developed according to these intelligences' capacities and functioning. While preparing the design of an architectural structure made up of billions of voxels for the fabrication, the machine manipulates it through the process; there, the design language, unique to architects, begins to disappear and leaves its place to the language of the *intelligent machines*. A similar transformation in the architectural language is observed in practices under morphogenesis, which tries to adapt the ability, order, and organization of non-human *living organisms* to both urban formation and architectural form-finding, material, and function. These studies show that the architects/designers aim to be the party in the merge between digital and biology, harbor a non-anthropogenic attitude, and arise due to the global energy crisis, environmental pollution, and damage caused by the accelerated production of industrial society. These approaches turn into generative processes in architecture that enable the exploration of spatial potentials through another living system.

New geometries, spaces, and parameters in architectural practice led to further material studies, and reciprocally new materials also create new potentials that enable unique formations. Material studies are separated into two that answer (5) *the **functional body** of modernism and the **aesthetic skin** of postmodernism, shifting towards more **integrative**, **holistic**, and **complex** unity.* These materials and structural systems can also transform, adapt, and mutate according to the data derived from the environment or parameters programmed to perform as intended. New motivations in architectural material include a technological one that adds sensory and interactive technical layers; and an ecological one that experiments with living cultures and habitable surfaces (wetware and hardware) and re-purposed, re-claimed materials.

New digital mediums such as video games, mobile interfaces, and social platforms (6) extend the boundaries of architecture both with **educative**, **interactive**, **communicative cyberspaces** and **experimental virtual spaces** that inhabit new potentials of architectural design, space, and perception. In that, video games may enable architects to design projects and typologies that have not been dealt with in real-life, consider new viewpoints, which is usually rare in daily life, and experience new design constraints of game mechanics like polycounts and performance issues. In the end, new digital spaces enhance the collaborative aspect of the new technologies by bringing together different professions from different industries which use the same tools but in very different ways.

The reflections of these industrial and architectural transformations in different regions differ depending on the economic conditions, development plans, and investments per country, as well as the research support, sufficient resources, and facilities of universities. In Turkey, artists, architects, and designers (games, graphic design) are widely involved in cyberspace and virtual space practices with the widespread usage of computers and networks. However, new technological systems and hardware are only implemented by a few architects under sustainable and intelligent building design. Digital fabrication techniques and material technology, on the other hand, contain a limited number of examples within the scope of current advancements. Nevertheless, in terms of the insufficient number of instances, there has not been a big difference between Turkey and other developed countries. Since the industrial technology and digitalization that have developed in the last 30 years have not spread to an urban scale and affected the society in this respect, these architectural practices mostly remain limited by their unique existence.

Within the negative side of impacts, such advantages and transformations mentioned so far in this thesis are also open to converting (7) *architecture to a mere **form of commodification**,* representing a divergence from its essential principles such as tectonic truth, contextuality, environmental sensitivity, meaning and timelessness and (6) *architects to **precarious and marginalized labor*** by including artificial intelligence and advanced computation into the design process.

Therefore, the transformations in industry and the impact of technology should be evaluated with a critical distance while celebrating new developments and possibilities. When the difficulty of doing research mainly concentrating on contemporary developments is concerned, this study is open to further alterations and alternative evaluations. Similarly, the plurality of titles and research areas leaves it open to further contributions and studies.

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APPENDICES

A. The Comparative Framework of the Outcomes

TRANSFORMATIONS IN ARCHITECTURE

	Early Decade of Digital Age | Digital Turn . From Standardized to Variability and Efficiency . Non-Euclidean Geometries	. CAD/CAM = Representation Tool and Generative Process . Software influence (CATIA, NURBS modelers)	. Fold, Curvilinear, Bloby, Fluid, Topological, Rubber-Sheet Expressions *Branko Kolarevic (2003), İpek Gürsel Dino (2012), Patrik Schumacher (2019), Mario Carpo (2019)*
			
Projects / By	**The Guggenheim Museum Bilboa**, 1993-1997. Gehry Partners	**Haydar Aliyev Center**, 2007-2013. Zaha Hadid Architects	**L'Hemisfèric, City of Arts and Sciences**, 1998. Santiago Calatrava
			
Projects / By	**Disney Concert Hall**, 1991-2003. Gehry Partners	**Dongdaemun Design Plaza**, 2009-2011. Zaha Hadid Architects	**Sage Gateshead**, 2004. Norman Foster

A. NEW POSSIBILITIES OF ARCHITECTURAL LANGUAGE

1. Post-Digital: The Language of New Digital

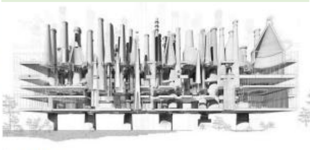
	Digital Materiality . language of immaterial . merge between the immateriality of digital and materiality of architecture. *Fabio Gramazio and Matthias Kohler (2008), Chris Anderson (2014).*	Digital Craftsmanship . language of AI | hand+mind . narrowing gap between design and construction; collaborative, interactive *Richard Sennett (2008), Mario Carpo (2011), (2012) Aukje Schukken (2016).*	Digital Morphogenesis . language of behavior | form-finding . new organizational, spatial potentials derived from the living organisms. *Branko Kolarevic (2003), Jonathan Bard (2008), Nick Dunn (2012).*
			
	P_Wall	**Digital Grotesque II**	**H.O.R.T.U.S. XL Astaxanthin.g**
By	A. Kudless, Matsys	M. Hansmeyer, B. Dillenburger	EcoLogicStudio
Year / Location	2006 / Banvard Gallery, Knowlton School of Architecture, OSU, Columbus, Ohio, USA.	2017 / "Imprimer le monde" exhibition, Centre Pompidou, Paris, France.	2019 / "Le Fabrique du Vivant" Centre Pompidou, Paris, France; Japan; Austria.
Dimension	15′ x 9′ x 1′ (4.57m x 2.74m x 0.3m)	3.45m height, 537 m^2 total surface area, 4m x 2m x 1m print space.	NA
Material	Plaster, elastic fabric.	Sand-printed elements (silicate+binder)	PETG thermoplastic, micro-algae, biogel.
Design / Fabrication Process	The point-clouds, created through the grayscale values of an image, are used to mark the positions of the dowels that limit flexibility in the fabric pattern. Plaster is poured into the mold within the limits of the fabric while expanding it with weight. They're assembled into a larger surface.	Design constituted from 16,386 design variations, 260 million surfaces, 42 billion voxels, 156 GB production data that are calculated on ETH EULER high performance computing cluster. After 2-year design process, it is 3D printed and assembled in about 1 month.	The substratum is designed as a porous shell and 3D printed in pieces. The assembled structure is infilled with bio-gel substance for Photosynthetic cyanobacteria to live, absorb CO_2 and produce O_2, biomass and energy.

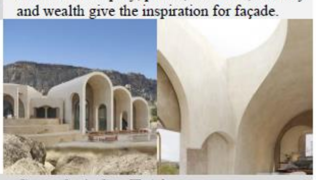
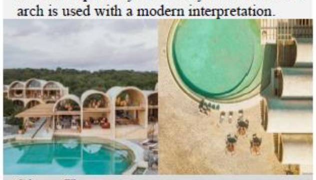
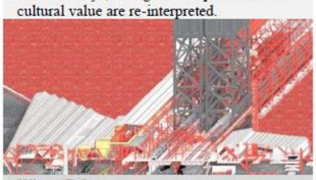
	Winery Gantenbein	**TECLA Houses**	**Boolean Operator**
By	Gramazio & Kohler, Bearth & Deplazes	Mario Cucinella Architects	Marc Fornes, Theverymany
Year / Location	2006 / Fläsch, Switzerland.	2021 / Massa Lombarda, Ravenna, Italy.	2018 / Jinji Lake Biennial, Suzhou Shi, China.
Dimension	400 m² façade	60 m²	735 sq. feet (68 m²)
Material	Concrete skeleton, 20,000 bricks.	Local raw earth mixture	1-2mm thick ultra-thin aluminum
Design / Fabrication Process	The façade design is created with a digital image data representing a "basket" of "grapes" with varying sizes. The brick wall is calculated by a computer and built by a robot using a programmed parameter. 72 wall elements are assembled with data informed robot's maneuvers.	7000 G-codes are used by two synchronized 3D printer arms that are controlled simultaneously over a software that optimize movements by avoiding collisions and ensuring the operation. They are built with 350 layers of 12 mm and average 6 kW energy within 200 hours.	The curved, twisted design and structure is determined by 3D analysis to come together as a single skin.

2. Post-Media: The Language of Old Media

. the new avant-garde no longer seeing or representing the world in new ways. . accessing and using in new ways previously accumulated media. . uses old media as its primary material. . new media is post-media *Lev Manovich (1999)*	. originality issue . copy-paste design = an obstacle to the development of architecture *Winy Maas et al. (2017)*	. copy-paste as a collage technique as an architectural manifestation of a critical thought. . digital platforms of accumulated post-media language. . experiments with the limits of elements *Bilge Bal and Bahar Avanoğlu (2019), Aitana Aguilera (2021), Renan Teuman (2021)*

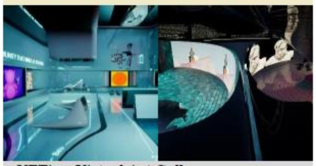
	Arches Boulogne, Social Housing	**Arcadia Cinema**	**Exodus**
By	Antonini + Darmon Architectes	Tracks Architects	Aitana Aguilera
Year / Location	2016 / Boulogne-Billancourt, France.	2018 / Riom, France.	2021 / digital - KooZA/rch
Dimension	2426 m²	1028 m²	NA
Material	White cast-concrete and others.	Volvic stone, concrete and others.	NA
Design Process	Arches of antiquity, power, erudition, stability and wealth give the inspiration for façade.	Arches inspired by the history of the site. The arch is used with a modern interpretation.	The chimneys, losing their importance as a cultural value are re-interpreted.

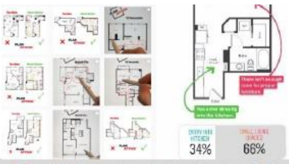
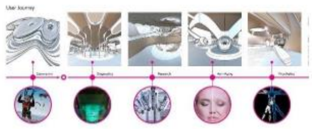
	Cappadocia Spa Hotel	**Sforza House**	**Wheat Belt**
By	Gökhan Avcioğlu	Taller de Arquitectura X	Renan Teuman
Year / Location	2020 / Cappadocia, Turkey.	2021/ Zicatela, Oaxaca, Mexico.	2021 / digital - KooZA/rch
Dimension	37789 m²	NA	NA
Material	Soft stone and others.	Sand-yellow bricks and other local materials.	NA
Design Process	Design strategies come from connections to the surrounding geography and history.	Vernacular traditions of the site inspire the blurred lines inside and out, arched ceilings.	Reproduces and re-uses the truss system as connecting and structural element.

B. NEW LIMITS OF SPACE IN ARCHITECTURE

. two bodies ordinary body and virtual body . real space that is tangible and virtual space, the realms of seamless medium. . flows of electron | user interface.	<u>Metaspaces</u> . spaces transcending the ordinary physical space | cyberspaces . spaces over other metaspaces | social media	. spaces exceeding the ordinary physical space | video games *Marshall Mcluhan (1964), Toyo Ito (2010), Antoine Picon (2010), PUBG X ZHA (2022), Aris Politopoulos et al. (2019), matthewnorth / instagram (2022).*

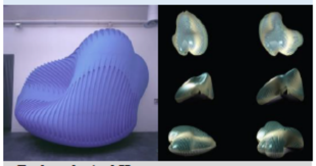
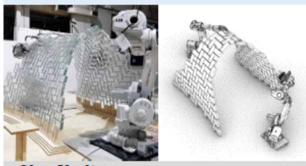
  

	Dominion Office Building	**NFTism Virtual Art Gallery**	**Athens in Assassin's Creed Odyssey**
By	Zaha Hadid Architects	Zaha Hadid Architects	Ubisoft Quebec, Ubisoft
Year / Location	2015 / Moskva, Russia.	2021 / cyberspace	2017 / video game
Design Process	Dynamic, fluid space design for the atrium.	"Software as a Service" built with MMO tech.	Anvil Engine is used as a game engine.

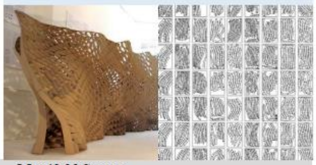
		
	Mass Collaboration in Architectural Plan	**Medical Center**
By	Matthew North	Zaha Hadid Architects
Year / Location	2022 / social media - Instagram	2022 / mobile game - PUBG
Design Process	Interface is used for people to participate.	3D software with game mechanics constraints.

C. NEW POTENTIALS IN MASS CUSTOMIZATION AND DIGITAL FABRICATION

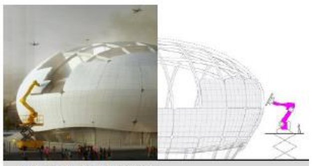
1. Mass Customization: Non-Standard Mass Production

	. computer-controlled mass production, fabrication technology, file-to-factory. . customizable, variations, more complex, less cost.	. second wave of digital fabrication from task-specific to computer-numeric, non-specific controlled production.	. establishes participatory relations. *Branko Kolarevic (2003), Kas Oosterhuis (2004), Achim Menges (2013), Mario Carpo, (2017), Greg Lynn (2019), Branko Kolarevic and José Pinto Duarte (2019).*
			
	Custom Prefab Homes	**Embryological House**	**Glass Vault**
By	Resolution: 4 Architecture	Greg Lynn	SOM, c.r.e.A.te lab and Form Finding Lab,
Year / Location	Website - www.re4a.com	2002 / Venice Biennale, Venice, Italy.	2020 /
Dimension	Customizable	Variable	7 feet (2.13m) height, 12 feet (3.66m) wide, 21 feet (6.40m) long.
Material	Customizable	Variable	Glass brick, epoxy.
Design / Fabrication Process	After designing the Conceptual Blocks, creates modules of essential areas in housing. Combines areas with a range of customizable typologies. By determining the basic type, an endless number of variations are manipulated through a software. According to the orientation, views, program, and others, these variations include Double-Wide, L, and Z typologies. Pre-designed modules are posted on a website for potential client to personalize	Using state-of-the-art technology of that time, the house and its variations were achieved through formal and spatial manipulations over Maya's Script Editor. These variations are generated with the combinations of 50,000 surfaces. One of the houses is digitally fabricated and assembled.	A cooperative design with robots and humans, where robots participate in the parts that require accuracy and spatial recognition while humans perform the tasks that require flexibility and real-time settings. The vault structure is created in-situ by two humans scaled, fixed-in-situ robotic arms. Rigid epoxy is applied between each brick by humans as a bonding material.

2. Digital Fabrication: Computer-Aided Design and Manufacturing

	. Laser Cutting CO2 lasers in 1970s in textile industry; two-dimensional end product; assemblage needed. . CNC Milling Machine CNC based tools, milling, routing, cutting; G-codes: short computer scripts; removing/carving technique.	. Rapid Prototyping Technique Stereolithography technique in 1980s; rapid solidifying material, correction needed; adding technique. . 3D Scanning Technique reading/scanning the physical object; through a digitizer or tripod-mounted box; digitally transmitted; reverse engineering.	. Robotic Fabrication working in non-cubic space; self-referencing its position; robotic limb; programmed sophisticated actions. *Nick Dunn (2012), Matsys (2004), LAVA (2006), Shiro Studio (2008), Erdal Inci "Inventory", GXN Innovation (2009), Isabelle Herold (2018), Dagmar Reinhardt et al., (2020), Gramazio Kohler Research (2018), Melike Altınışık Architects (2023)*
			
	Manifold Screen	**The Radiolaria Pavilion**	**The Rock Print Pavilion**
By	Andrew Kudless, Matsys	Shiro Studio, D-Shape	Gramazio Kohler Research in ETH Zurich
Year / Location	2004 / Architectural Association, London, UK	2008 / Pontedera, Italy.	2018 / Winterthur, Zürich, Switzerland
Dimension	NA	3m x 3m x 3m, 27 m^2.	11 x 3m pillar height.
Material	3-mm solid cardboard.	Inorganic binder, sandstone.	30 Ton granular stone, 120km string.
Design / Fabrication Process	The honeycomb system is developed through several software, including Maya Mel script, Rhinoceros, form*Z, and AutoCAD within the research of integrating material system, design, and performance. Material is laser cut and comes together with folding and binding techniques. The biomimetic inspired the self-organizing internal system and the alignable hexagonal geometry.	CAD drawings are used and translated by the d-shape into the 3D layering information. The fabrication process includes the world's largest 3D printer at that time, having a 6m x 6m area and 12m height working space. The binder material is layered with a 5-10mm coating series by adding the technique.	Previously researched jamming and aggregation techniques inspired the project for the pavilion's pillars. The digitally controlled fabrication process includes a construction robot called an in-situ fabricator. The robot adds layers of string and granular material to ensure the stability of the pillars.





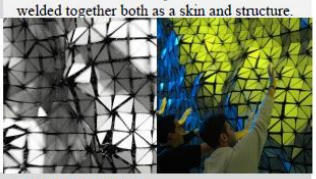
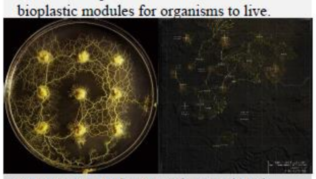
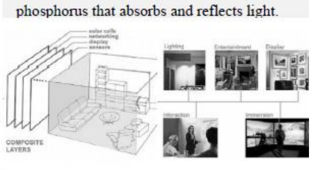
	Entry Paradise Pavilion	Louisiana Pavilion	Robot & AI Museum
By	Chris Bosse, PTW Architects	3XN.	Melike Altınışık Architects (MAA)
Year / Location	2006 / Zollverein, Essen, Germany.	2009 / Humlebaek, Denmark	2023 / Seoul, South Korea.
Dimension	7m x 7m x 7m, 49 m^2	NA	2500 m^2
Material	High-tech Nylon and light	Polystyrene foam, flax fibres cast, 1mm solar cells cast, LED lights.	Metal, concrete.
Design / Fabrication Process	It is the result of the experiments with irregular natural formations. Software of Taiyo membranes is utilized in the process, and a CNC laser cutter with a 5m table is used to constitute the pieces. Only 17 kg reusable pavilion pieces are transported in a small bag, can be assembled / dissembled within an hour.	With the physical model, folding and curving potentials are explored to determine the form of the project. Through 3D scanning, the physical model is transmitted into digital information. With the digital model, the process pursues further arrangements of molding, casting, and test-assembly processes.	With an emphasis on space designed for robots and their visitors, it will be fabricated by robots with a semi-automatic process. The material of the project will be prepared by the team of these machines. Drones will be involved to keep track of the construction and maintain security and inspection.

D. NEW MATERIALITY IN ARCHITECTURE

Spatial Motivation	Ecological Motivations	Technological Motivation
diminution of importance of distinction between load-bearing/non-load-bearing | multidimensional, reflective, dynamic | merged and holistic structural system. *Branko Kolarevic (2003), Blaine Brownell (2006), Christian Schittich (2008), Maria Voyatzaki (2009), Moritz Fleischmann et al. (2012).*	synthesis of digital with the intelligence of non-human living organisms as an attitude toward humanity's intervention in nature. *Antonino Saggio (2003), Urban Morphogenesis Lab (2015, 2016, 2017), Claudia Pasquero and Marco Poletto (2020), Hatice Ay (2020), Hayriye Kaya and Arzu Susan (2020).*	interactive, adaptive, and sensory additions of digitalization into new materials; integrating technology into building fabric; and redefining the architectural elements. *Blaine Brownell (2006), Osman Ataman (2005).*

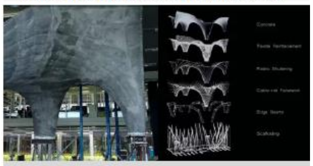


	ETHER/I	Algae Curtain	The Give Back Curtain
By	Mark Goulthorpe, dECOi Architects.	EcoLogicStudio, Urban Morphogenesis Lab.	Kennedy & Violich Architecture
Year / Location	1995 / Geneva, Switzerland.	2018 / Climate Innovation Summit Dublin UK	NA
Dimension	NA	16 x (2m x 7m)	NA
Material	Double tessellated surface of aluminum.	Micro-algea, bioplastic.	Fabric, photoluminescent pigments
Design / Fab. Process	4000 non-standard components is cut and welded together both as a skin and structure.	Habitable serpentine tubes are attached to the bioplastic modules for organisms to live.	The fabric is woven with luminous phosphorus that absorbs and reflects light.

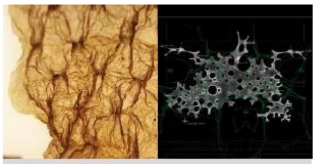




	Aegis Hyposurface	Physatopia - Urban Morphogenesis Lab	Digital Wallpaper Prototype - Research
By	Mark Goulthorpe, dECOi Architects.	Jiayi Tu, Qin Qing	Osman Ataman
Year / Location	2007 / BIO I. Convention, Boston, USA	2017 / The Bartlett, UCL, UK.	2005
Dimension	3m x 10m	NA	Variable
Material	896 pneumatic pistons, electronic, metal.	physarum polucephalum	Flexible electronic circuits, paperlike display
Design / Fab. Process	A multi-faceted metallic surface responds to its environment with sensors and pistons.	Digital process is done through algorithmic stigmergy and agent-based models.	A flexible active-matrix surface can be formed based on silkscreen/inkjet printing.





	Winnipeg Skating Shelters	Biocement - Urban Morphogenesis Lab	NEST HiLo Roof Shell
By	Patkau Architects	C. Chen, Y. Zhou, Y. Hu, H. Liu, W. Ye.	Philippe Block, Arno Schlüter, ETH Zurich.
Year / Location	2011 / Winnipeg, Canada.	2015 / The Bartlett, UCL, UK.	2017, ETH Zurich, Switzerland.
Dimension	NA.	NA.	7.5m height, 160m^2 surface, 3-12cm thickness
Material	Flexible plywood layers.	Sand, cyanobacteria and chemicals.	Concrete, insulation, thin photovoltaic cells.
Design / Fab. Process	bending and deformation, cuts and openings of two-layer thin plywood.	The combination of special liquid and sand turns into a cement-like structure.	The shell structure is made of layers of formwork.

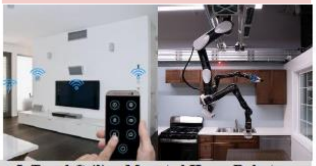

	Prada Sponge Wall	**Microbialcellulose**	**BL Special Experiments**
By	Rem Koolhaas, OMA.	L. LI, P. LI, W. HUANG and X. XIAO	Steven Holl
Year / Location	2002 / Prada store, Los Angeles, USA.	2016 / The Bartlett, UCL, UK.	2006
Dimension	300 m² storey.	NA.	NA.
Material	Translucent cast resin and silicone mats.	Bacteria yeast and microorganisms.	Ultra-thin wood, paper and fabric.
Design / Fabrication	Inspired by the cleaning sponge, the design comes out with several tests and prototypes.	A new substance called microbial cellulose is made with a symbiotic mixture that organisms	The design comes together with the lamination of different materials that



	Burnsville Performing Arts Center	**Mehr.WERT.Pavillon**	**Hy-Fi**
By	Ankeny Kell Architects	2hs Architekten und Ingenieur PartGmbB	David Benjamin
Year / Location	2009 / Burnsville, USA.	2019 / BUGA: Federal Garden Exhibition, Heilbronn, Germany	2014 / MoMA PS1's Young Architects Program Winner, New York, USA
Dimension	69,000 m²	NA	12m height
Material	Panelite IGU, backlit with LED and others.	Recycled and reused glass, steel, plastics, and mineral.	10,000 (shredded corn stalks and mushroom mycelium) bricks.
Design / Fabrication Process	Light embedded transparent columns are used to enhance the definition of entrance space. The columns are made of recombinant material that consists of multi-separate layers.	Re-claimed steel is used for load-bearing skeletons; recycled bottles, and industrial glass are used for façade and roof cladding; HDPE plastic waste is recycled into chairs that are 3d printed; demolition waste and minerals are used for floors in landscape.	The stackings of composable bricks in free-from structures are designed through a computational process for a steady and stable result. The experiments through software in the process offer variable possibilities of construction.

E. NEW ADDITIONS TO ARCHITECTURAL HARDWARE

buildings as a never-ending complex construction *William J Mitchell (1996), Lev Manovich (2002), Martin Lister et al (2009).*	hardware (Processor, graphic card, and RAM) as a design-accelerating attribute. *Lev Manovich (2002), Martin Lister et al (2009).*	. green building systems . improving social and economic health, moderating environmental degradation through conservation, reduction of pollutants, protection of water and natural resources and habitats *Frank Ching and Ian M Shapiro (2014)*



	IoT and Ceiling Mounted Home Robot	**Render Comparison**	**Türkiye Müteahhitler Birliği Merkezi**
By	Toyota Research Institute (TRI).	Vray and Twinmotion	Avcı Architects
Year / Location	2020	NA	2013 / Ankara, Turkey
Dimension	NA	NA	6.900 m² total area
Material	Aluminum extrusion, robots	Average computer hardware.	Construction materials including local materials
Design / Fabrication Process	Robots are tested with a ceiling-mounted technique similar to the movement of a CNC milling machine by using x and y axes. The path is constituted by aluminum extrusions attached to the ceiling and the direction of robots is limited within that pattern	According to the software's minimum system requirements, hardware such as graphics cards, CPUs, GPU, and ram become essential elements for the correct execution of the design and construction.	LEED Platinum certificated building is designed by paying attention to the transparency of interior and external relations and its construction. Office building embodies active and passive systems with several complex additions to minimize energy consumption, temperature, and air control.