“Digital design” and three flows of ideas

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1. Introduction

1.1. Background

Along with the development of cutting-edge digital technologies, innovative approaches in architectural design are advancing by leaps and bounds. The scope of exploration spans over a modeling technique of controlling parameters and algorithms, form-finding through evolutionary structural optimization (ESO), material-driven design, thermal and lighting analysis simulation, and AI-based design automation, far exceeding mere free-form studies shown in the past.

This study was triggered by a question that this current trend of probing technological applicability in architectural design would be a distinctiveness of only contemporary era. Indeed, discourses on digital technologies in the field of architecture have a long history; considering their dawning to be the 1960s right after World War II is a general perception. It is when the computer was invented. Leslie Martin of the University of Cambridge in the United Kingdom, Lionel March, Christopher Alexander, and Peter D. Eisenman aimed for articulating design thinking through mathematical methodologies, while Frei Otto of Stuttgart University established the Institute of Lightweight Structure (IL) and scrutinized building techniques resembling laws of nature. Around the same time, Archigram and Cedric Price explored and delineated imaginations on the future, attainment that highly influenced contemporary architects such as Richard Rogers, Norman Foster, and Zaha Hadid. Furthermore, they commonly appear in the discourses on forms and images of architecture integrating digital technologies.

This study’s hypothesis is formulated on the idea that current trials and experiments over the interface of architecture and digital technologies are essentially stimulated by the “idea” formed around the 1960s. By tracing its historical sequences, this study aims to organize the flows of “digital design”, which seems quite sporadic, and reinterpreting their significance from a diachronic point of view.

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1.2. Object and terminology

Terminologies frequently used regarding digital technologies in architecture include “digital architecture”, “digital design”, “parametric design”, “computational design,” and “freeform architecture.” Especially in South Korea, the term “freeform architecture” indicates all buildings with “not formal” shape, and it is often interchangeably used with “digital design”. Its connotation, however, emphasizes morphological aspects so that it cannot denote critical characteristics of “digital design” such as quantification, rationality, or arithmetic operations. Therefore, the term “freeform architecture” does not correspond to the main objective of this study. The tendency of associating morphological aspects like “complicated” and “free curve” with digital technologies seems to be rooted in the previous narrative style of architectural history focusing on “style.” This tendency will be further discussed in the next chapter.

“Parametric design” does not distort the fundamentals of digital technologies as freeform architecture in that it stands for the design that utilizes parameters. Yet, as Patrik Schumacher, a former partner of Zaha Hadid, coined the term “parametricism” and tried to situate it as a new style of the upcoming era by presenting their characteristic 3-dimensional curvilinear surfaces, morphological aspects were magnified as well (Schumacher 2009). Schumacher retracted some of his arguments in his book in 2018, but the term parametric is still almost synonymous with “curvilinear” or “complicated” in the field of architecture.

“Computational design” is another widely used term, literally indicating the utilization of computer’s abilities as well as the capacity of computational arithmetic operations or computer-aided design. Using the term does not distort the fundamentals of digital technologies, thus the term itself is very close to the topic dealt in this study.

This study avoids using those terms that magnify only certain aspects of digital technologies. Moreover, when referring to “digital design”, this study is looking at the achievements influenced by digital technologies in design thinking, intention, and idea beyond drafting and 3D modeling during the actual design process. Discourses on digital technologies can be further expanded by using more integrated and balanced terms.

1.3. Composition and objective of study

Chapter 2 deals with various categorizations and perspectives of “digital design” previously constructed by many scholars. Some scholars such as Charles Jencks, William Curtis, and Bill Addis situated “digital design” as a part of the whole architectural history. Their writings and books are studied to discover related discourses after the 1950s. Meanwhile, after the 2010s, “digital design” began to be viewed apart as an independent subject of historical narrative. For this tendency, studies of well-known architectural theorists after the 2010s, Antoine Picon, Mario Carpo, and Sean Keller, were mainly analyzed.

Chapter 3 integrates various perspectives studied in the previous chapter by drawing three flows of ideas “Mathematics and Function,” “Nature and Structure,” and “Imagination and Form” based on the analysis of the ideas that appeared around the 1960s.

Chapter 4 looks at the historical development of these three flows of ideas. Works of corresponding architects, theorists, and scholars are considered at various levels, and their associations are examined. Furthermore, how they are connected to the “digital design” after the 2010s and technological progress meantime has created differences are analyzed in detailed case studies.

2. Perspective of established architectural theory on “digital design”

The first step is to deduct valid perspectives and keywords for tracing the flow of “digital design” by scrutinizing the studies after the 2010s.

2.1. “Digital design” as a part of post-modernism in history of style

Typical historical narratives considered “digital design” as one part of various contexts within post-modernism. Charles Jencks has undoubtedly made his presence felt in this perspective; his four books on post-modernism, including “the Language of Post-modern Architecture,” published in 1981, categorized architectural works after the 1920s with thematic keywords and analyzed each tendency. Major flows are expressed in a diagram shown in Figure 1. In his recent book “The Story of Post-Modernism,” as shown in Figure 2, some keywords like biomorphic, fractal architecture, cybernetic, and folding are presented to have a direct relationship with digital technologies (Jencks 2011).

They are related to mathematical rules observed in nature or stimulus of new technology, computer. These keywords, however, appear in the diagram around the

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1 Parametricism – A New Global Style for Architecture and Urban Design, Patrik Schumacher, London 2008 Published in: AD Architectural Design – Digital Cities, Vol 79, No 4, July/August 2009, guest editor: Neil Leach, general editor: Helen Castle
2 Jencks’s four books on post-modernism are as follows. Jencks (1981) The Language of Post-modern Architecture (rev enl ed.), New York: Rizzoli; Jencks (1986). What is Post-Modernism?, London; New York: Academy Editions; St. Martin’s Press.; Jencks (1990). The new moderns: From Late to Neo-Modernity. London: Academy Editions.; Jencks (2011). The Story of Post-Modernism: Five Decades of the Ironic, Iconic, and Critical in Architecture. Chichester, West Sussex: Wiley.
1990s throughout the overall flow and are situated with deconstructionism. Is this association relevant? Is there a possibility of any different correlation? What if their rudimentary base has resulted from ideas before the time period? More intensive contemplation on these issues seems necessary.

Categorization of flow rather depends on the morphological outcomes than the design process or fundamental intention. This tendency ultimately contributed to contemporary discourses on “digital design” to be emphasizing morphological aspects much more than the essential influence on design process and thinking. Also, theoretical experiments and discourses in academia are underrepresented, while works of architects are extensively used as references. This study aims for more balanced perspectives by considering experiments conducted by thinkers, theorists, or even a department in universities or institutes as well.
2.2. “Digital design” with emphasis on individuals or theories

Antoine Picon is a representative historian who tried to delineate the history of “digital design” as an independent subject. The first chapter of his book “Digital Culture in Architecture” briefly summarizes discourses and works related to “digital design” from the 1950s to the 2000s (Picon 2010). His keywords include “information,” “computer,” “cybernetics,” and “formalism.” Flows after the 1990s are categorized into two major movements: “Experiments in Form and Performance” and “From Tectonic to Ornament.”

He demonstrates his own perspectives on the ornamental manifestation of facades in virtue of the development of digital technologies and the revolution of manufacturing techniques, an idea that is clearly shown in “Ornament: The Politics of Architecture and Subjectivity” published in 2013. Through focusing on “Reemergence of Ornaments” which was a part of his previous works, he tries to expand this context into overall architectural history. His perspectives on the relationship between digital technologies and changes in facades are effective in grasping certain aspects of “digital design”, but there is a limitation in a comprehensive understanding of “digital design”, including recent attempts after the 2010s such as simulation or optimized methodology, their application in the design process, and corresponding innovative material usage.

Sean Keller’s “Automatic Architecture”, published in 2017, is a historical narration focused on the ideas and methodological innovation of Christopher Alexander, Peter Eisenman, and Frei Otto around the early 1960s. Its significance lies in his stance on emphasizing how technologies inspired ideas and influenced logical design thinking beyond the palpable maturity resulting from technological development. In this kind of viewpoint, “flow of idea” is centered on interpreting relevant academic movements and a group of architects. This viewpoint seems valid to understand contemporary experiments. Therefore, the later part of this study focuses on the origin of the “idea,” its historical development, and contemporary significance.

2.3. “Digital design” with emphasis on changes in design methods due to technological development

Bill Addis narrated architectural history with a focus on technological development. (Addis 2007) The last part of his book is on “digital design”, and it is interesting that he regards it as a new material, neither a tendency nor an action.

Among the various aspects of “digital design” reviewed in this study, “computational perspective” or scientific approach was examined in Rocha’s dissertation: how they were developed in major research centers of universities in the United States and Britain from the 1960s to 1980s. (Rocha, 2004) He identified the discussion of the relationship between art and technology by intellectuals debated during the First and Second World Wars, the increase in technological demands related to cities and architecture, and the resulting interdisciplinary collaboration as primary backdrops for the rise of research on a culture of computational and scientific approach in architecture. Upitis reviewed events related to the Design Methods Movement and associated discourses of academic conferences from 1944 to 1967. (Upitis, 2008) Then, he examined how computational design and related research influenced the design process in architecture. According to her dissertation, not only technological but also psychological concepts brought about a change in the interpretation of the relationship among nature, social culture, and norms used in the field of architecture.

Meanwhile, Daniel Cardoso Llach gave an account of changes in contemporary architecture resulting from digital technology, such as the Computer-Aided Design Project’s influence at MIT in the United States during the 1960s or the recent BIM’s impact. (Llach, 2012) He argues that the most significant change is to negate the traditional distinction between architectural design and construction so that designers can participate in the decision-making steps of the whole process, even in technical or construction parts.

These dissertations reflect perspectives that digital technology has changed the concept and design methodology of contemporary architecture to a great extent. While the above-mentioned studies focus on examining how the design methodology derived from advances in digital technology has been developed, they do not deal with the designer’s intention, orientation, and vision in the realm of architectural design.

In his book “The Second Digital Turn”, Mario Carpo deals with changes in design methods due to the leap of digital technologies. (Carpo 2013) He regards explorations on “digital design” in the field of architecture during the 1990s as “the first turn” while “the second turn” refers to the innovation in technology-oriented design methodologies after the 2010s. Whereas the first turn was comprised of emergence of mass-customization owing to newly-introduced CNC technology in the early 1980s and explorations in free form shapes,
the second turn can be summarized as design optimization and simulation in virtue of big data. As to construction techniques before the 2010s, Carpo illustrated the process as a scientific method of the modern era: composing principles or formulas through data-compression from outcomes of dynamics and processing necessary calculations to find out general solutions through data-extraction. Meanwhile, after the 2010s, a new design methodology based on simulation and optimization aimed at finding one particular, best-working solution by allowing computers to operate numerous trials and errors under given conditions. Carpo’s perspective is legitimate in that technological development plays a major role in changes in design methods and thus can help contemplate the differences between previous experiments and contemporary ones in “digital design”. Together with Keller’s perspective discussed before, it proves to be valuable in tracing how pre-existing ideas that could not be actualized due to the limitation in technologies are ultimately manifested in the contemporary era.

3. Three flows of ideas within the scope of “digital design” and their historical development

In the previous chapter, precedent studies’ perspectives on “digital design” are considered. The traditional chronological narration was restricted to verification of association among works of a similar time period, thus emphasizing the stylistic aspects. At this moment, it is necessary to rethink the term “digital design” that we often use off the top of our heads. As Neil Leach stated in 2002, the term “design” sometimes refers to the design process while it can also refer to the outcome of a design proposal in a specific form. When the term “digital” is added to form a phrase “digital design”, we can deduce three categories of interpretation as follows.

First, regardless of the design process – even if design is done in a traditional way – when the outcome bears resemblance to “digital design”. In this case, the designer follows a traditional process of sketching by hand and transferring it to CAD for computer drafting. However, it shows a streamlined shape, and structural elements such as trusses are emphasized, or shiny metal materials are mainly used in its skin. In this case, the architect’s character or formative concept is emphasized rather than digital technology or related ideas.

Second, cases in this category use the latest “digital design” methodology, but such a process is not clearly reflected in the appearance. For example, openings or pattern of the façade is determined through daylight simulation, and floor plans are designed through circulation simulation or analysis. However, they are still similar to “traditional” modern architecture in form. In this case, without a detailed elaboration on the process, the trace of “digital design” methodology cannot be found. Digital technology is only used to achieve the rigor of the scientific design method, and rationality is underscored, but whether the form mirrors its design process does not matter.

The third category includes the cases in which the design process and the outcome are largely influenced by “digital design”. Grasshopper and other plug-ins (form-finding software such as Kangaroo) and programming languages such as C# and Python are used during the design process, so designers can produce a unique and unprecedented form that is difficult to formulate without the help of such software.

Furthermore, if we look at historical examples representing these three categories of interpretation, it is interesting to note that they converge with certain “orientation point,” “architect’s intention,” and “architectural idea or theme” of a specific architect or a group of certain architects.

First of all, the tendency to prioritize human intelligence, logic, and rationality over anything in the design process may have its origin from the stance of Christopher Alexander and Peter D. Eisenman during the early 1960s, as stated by Keller. Also, in this time period, a definition of architects’ function was facing the whole new vistas. Before the war, the traditional role of architects was confined to artist-craftsmen specialized in small-scale projects. After the war, however, there was a drastic increase in the need for big-scale buildings and the reconstruction of cities. To meet the needs of the times, architects began to pay attention to scientific methodologies and mathematical models to be credited for expertise to stand beside engineers and city planners. This shift reached the peak at the University of Cambridge with Leslie Martin in the lead. At that time, Cambridge was filled with a passion for technologies that insomuch called Fenland Tech (Keller 2006). Leslie Martin, who served as a founding dean here after 1956, previously issued “Circle: International Survey of Constructive Art” with Moholy-Nagy, Siegfried Gideon, Walter Gropius, and Le Corbusier in 1937, where they introduced the innovative development of science and technologies and argued that architecture and art should parallel that achievement (Keller 2018). Since then, the Department of Architecture at Cambridge was home to many prominent figures of architecture, including Peter Eisenman, Colin Rowe, Christopher Alexander, Lionel March, and so on. They raised questions on previous design
processes hinging on subjective experience and intuitive design-making and tried to define all design processes in accordance with the logical association through mathematical models. This kind of effort is further manifested in the optimization methodology, which utilizes a building’s functions and site conditions as input variables. In this study, the first flow of ideas is defined as “Mathematics and Function.” Its design attitude and significance will be further discussed through relevant projects in section 4.1.

On the one hand, the 1960s also faced a backlash against the machine civilization brought up by wars, thus confronting a strong desire for regression towards nature (Curtis 1996). For instance, contrary to the “heavy and permanent” construction style with its iconic massive dome during the era of imperialism, the “light and temporary” construction style was pursued. Also, there were trials in form-finding based on construction principles or rules of nature. Especially, the form-finding process according to structural principles is still actively embraced by contemporary architects. As Keller stated, this tendency was derived from famous experiments of Frei Otto who was endowed with original ideas, such as “minimal form-making with soap film” or “catenary line modeling with metal chains.” Although recognized as innovative, this design method was not popular at that time because it required voluminous mathematical, mechanical expertise and complicated machine tools as well. Carpo pointed out that during the 1960s, only IL with expensive facilities was capable of those experiments; however, after the 2010s, ordinary personal computers could operate “simulations,” thus allowing any architect to conduct such architectural experiments similar to the means of Frei Otto. This flow of ideas is referred to as “Nature and Structure” in this paper. This second flow of ideas is explained in section 4.2. This keyword and the first one, “Mathematics and Function,” present differences in form-finding method and viewpoint on computers. Whereas Alexander prioritized humanistic conditions; Otto put laws of nature ahead of everything. Moreover, Alexander regarded computers as an objective, while Otto used them as the means.

All of Jencks’s keywords “deconstructionism,” “formalism,” and some other architects focused on the creation of free-form shapes. Their shapes could be realized through CNC techniques, but human imagination, architectural expression, and each individual architect’s style were in priority of such works. Frank Gehry’s works can be exemplified to illustrate how formative aspects of architecture have gravitated towards an architect’s intuition rather than technological development for the last few decades. Prioritizing architectural imagination through inspiration by technological development over the actual technologies has similar roots with Cedric Price and Archigram in the early 1960s. Then, it had its heyday together with CNC techniques, introduced in the 1980s and widely used since the 1990s, and mass-customization. Carpo summed up this movement as “conquest of free form,” whereby form-making rules over the overall logic and process so that technologies function as mere tools. This study’s third flow of ideas, “Imagination and Form,” is further discussed in section 4.3. Contemporary perception of “digital design” as such belongs to this flow. Visual intensity and symbolism are at the hub within this flow, and here are familiar projects often discussed in the architectural history-related discourses of post-modernism. However, at this point, its significance does not overwhelm two other flows, so in this paper, three of them are positioned in an equal hierarchy to open up balanced discussion.

4. Historical development of “digital design” and three flows

In this chapter, three flows of ideas, “Mathematics and Function,” “Nature and Structure,” and “Imagination and Form” are studied in terms of their historical formation and significance.

4.1. Mathematics and function

Computers during the 1960s could not visualize data very well; therefore, their utilization was confined to a rather conceptual application than modeling or rendering, which sounds familiar these days. The architectural design process was identified with problem-solving under given conditions, and each parameter, association, and formula was applied to a design methodology as logical arithmetic operation. Christopher Alexander was a trailblazer in this flow, insisting on the exclusion of personal experience or own perspectives during the architectural design process. In his doctoral thesis, Notes on the Synthesis of Form, design elements and conditions were substituted as requirements, and each of their correlations regarding circulation, space, area, and orientation is plugged in mathematical formulas to draw out critical conclusions during the design process.

Figure 3 shows the design process of an Indian village. All necessary conditions were substituted with variables and listed. Then, their correlations were expressed in equations, calculations of which helped the deduction of design proposals.

An algebraic methodology was inherited along with architecture scholars of Land Use and Built Form Studies (LUBF), including Lionel March. March

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9William Curtis refers to two groups of Le Corbusier’s early work (Villa Savoye) and later works after the wars (curves and free form, Colline Notre-Dame Du Haut, Ronchamp) that show significant contrast.
reinterpreted Mies Van der Rohe’s Seagram Building through Boolean Operation, one of the mathematical modeling algorithms, as shown in Figure 4 (March 1976). He tried to exclude intuition and artistry and to emphasize mass creation principles during the architectural design process. (March, Steadman 1974)

Around the same time, Gordon Pask suggested the concept of cybernetics and mathematically defined architecture’s programs to express the relationship among space in algorithms. He implied that architecture could be designed based on scientific methodologies in statistics, psychology, and sociology (Matthews, 2006). On the basis of this idea, Cedric Price presented a project called Fun Palace. As shown in Figure 5 and Figure 6, a building’s overall composition was determined by the correlation between function and circulation. This stance was also stressed in the façade design, where structure and facilities were exposed.

Another representative case, as shown in Figure 7, where a reasonable solution was sought based on given conditions, is the British Museum’s Great Courtyard designed by Norman Foster in the late 1990s and constructed in the early 2000s. Requirements include the original courtyard’s width and length and the new central exhibition hall’s circular mass. A solution would be the immaculate geometry to enclose all of those (Williams, 2001).

Until the early 2000s, such intricate mathematical calculations and integrative design software were not available, but as algorithm-based modeling software became popular among architects

Figure 3. An entire village in India (Alexander 1964).

Figure 4. Boolean description of the seagram building (March 1976).
after the 2010s, it is an accessible methodology for ordinary architects as well. Its strength lies in the precise definition and controlling of the design process through variables and formulas, thus being applied to those particular buildings that require definite function or regulations such as sports stadium, theater, and concert hall. For instance, HOK or Populous specialized in the design of stadiums established their own manuals and programs by prescribing necessary conditions such as sectional slope for seat configuration or height of stair landing into functional formulas. “Siza Grammar,” devised by Jose Pinto Duarte of MIT Department of Architecture in 2005, analyzes Alvaro Siza’s housing design and organizes it into a sequence of necessary steps. In each step, users input variables and get the design outcome. As shown in Figure 8, he tried to verify that even a certain architect’s style can be reproduced through “computation” while meeting the needs for functions (Duarte 2001)

This stance hinges on the belief that clearly knowing the requirements can generate definite solutions. It is even more activated after the 2010s through interdisciplinary interaction and technological development in machine learning and artificial intelligence, in

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**Figure 5.** Cybernetic diagram of the fun palace program by Gordon Pask (1964, cedric price archives).

**Figure 6.** Plan of the fun palace by cedric price (1964, cedric price archives).
4.2. Nature and structure

Trials to infer architectural principles through nature can be traced up to the late 18th century when the preliminary idea of modern architecture was emerging (Forty 2000). Quatremerre de Quincy asserted that architecture does not only superficially imitate the shape of nature but also reproduce its construction principles (De Quincy 1788). William Chambers had a similar viewpoint and expressed the structure of “primitive buildings” as the Figure 9 (Chambers 1759). “The first sort of hut” resembling a tent influenced Frei Otto’s views on nature later (Keller 2018).

Otto extended the abstract application of construction principles observed in nature and devised unique form-finding design methodologies using metals, soap film, and so on. As can be seen in Figure 10, he created looped curves with wires, put soapy water on them, observed soap films created, and recorded their shape. Starting from the belief that minimal surface with maximal volume makes the most efficient space, this methodology is directed towards the design process that seeks a minimal surface to cover given perimeters. An architect controls conditions and perimeters, and the law of nature creates the shape. This stance is highly different from previous perspectives that considered nature to be quicksilver and impermanent (Keller 2018). Furthermore, it can be distinguished from the previous design method, which gives authority of form-giving to architects considering functional requirements. Otto’s German Pavilion at the 1967 International and Universal Exposition or Munich Olympic Stadium in 1969, as shown in Figure 11, clearly represent this attitude.

Design attitude of form-finding is experiencing its renaissance these days as computer operational capacities have reached the great leap after the 2010s and allowed structural optimization simulation. The flow of loads, materiality, and structural efficiency are valued in new construction methods, as shown in Qatar National Convention Center by Arata Isozaki. Figure 12 is a schematization of columns’ shapes generated by Bi-directional evolutionary Structural Optimization technology.6

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6Antoine Picon, “Ornament of the City,” in Preston Scott Cohen, Lightfall, Genealogy of a Museum: Herta and Paul Amir Building Tel Aviv Museum of Art, Milan, Skira, 2016, pp. 29–31.
7Structural Optimization can be divided into size optimization and topology optimization. Size optimization works through adjusting sectional diameters of frames or truss members to draw out the most suitable shape of structural members with minimum materials, and it is the most easily understandable optimization process. Topology optimization first assumes one continuum structure and finds the optimized form through controlling material
Figure 8. Partial tree diagram showing the deviation of basic patterns, types, subtypes, and layouts (Duarte 2001).

The Institute for Computational Design (ICD) at the University of Stuttgart, led by Achim Menges, actively conducts architectural experiments on construction optimization considering materialities and structural shapes observed in nature.

His Research Pavilion (Figure 13), built from 2012 to 2016, introduced carbon fiber composite whose strength-ratio for weight is ten times higher than aluminum or steel and utilized a 6-axis robotic arm that can wind threads in 3-dimensional space with a margin of error less than 0.06 mm. Figure 14 shows a model for the real-time analysis on the structural performance of the 2012 pavilion, which depends on the shape of reeling carbon fibers, the number of reeling, and the degree of overlapping. Through modeling, an architect can adjust various conditions and check real-time simulations on corresponding changes – that is, tracing one "working" solution through repetition of simulated trial and error. This process is similar to that of masters before the modern era establishing their know-hows through numerous trials and errors by manual works, but this one is a compressed version that can be done much quickly.

Neri Oxman’s Aguahoya project (Figure 15) liquefies kitosan, which is commonly found in nature, and sprays it to create a structure. The ingredient’s materialities, concentration, spraying speed and direction, and time for solidification are considered in the optimization process. This may be viewed as an acme of this nature-imitation stance in that not only natural structure but also the same logic of its formation system is applied. (Oxman 2010)

4.3. Imagination and form

The other flow of imagination on the future, its visualization, and emphasis on expressive nature has its roots in British architects around the 1960s. This flow is sometimes classified as “Neo-futurism.” Cedric Price’s Fun Palace, as discussed before, proves its significance in another aspect as well, apart from the optimization of functions. As shown in Figure 16, His drawing on the future of architecture depicts a huge space full of machine facilities, an image that directly influenced the design of the Centre Pompidou (Hernández 2015). Also, it later influenced the formation of architectural prototypes for mega-scale spaces such as airports and train stations.

Meanwhile, Buckminster Fuller’s entry to the 1967 International and Universal Exposition in Montreal (Figure 17) had budded from his aspiration for new architecture in the age of Radio (Wigley 2015). Since then, this imagery has played a critical role in other architects’ imaginations for future architecture. His intention could be interpreted in two ways: one to
create a “light dome” to negate “heavy dome,” which was an emblem of authority in the previous era, and another to disaffirm hemisphere and materialize the absolute dome – that is to create maximal volume with minimal building area (Keller 2018).

Neo-futurism architecture coincides in its form building with “digital design”. A majority of its early ideas could not be implemented in reality. New technologies were indispensable to produce futuristic architecture different from previous ones.

Charles Jencks stated that Fuller’s sphere subsequently evolved “blob” by Archigram and Greg Lynn (Jencks 2011). In the 1960s, their “morphological ideal” could not be realized due to the limitation in construction technologies, but it could be gradually achieved throughout the sequence of Numerically Controlled machines in the 1950s, the invention of NURBS that demonstrates 3-dimensional splines in the 1960s, and finally welcoming its culmination through CNC technologies in the 1980s.

Archigram’s Walking City or Instant City could not be constructed in practice at the time, but their architectural potentials were continuously studied by the later generation, especially those who represent a so-called “Blob” with a distinguished figure Greg Lynn. In fact, their ideas were actualized at Kunsthaus Graz in 2003 which is 30 years after the original ideation (Figure 18).
Likewise, the notion of targeting future-like form-making by active utilization of computer techniques can still be found in the works of not only Greg Lynn, but also Norman Foster and Zaha Hadid. (Lynn 1998) For instance, blobitecture, a term coined by Greg Lynn refers to buildings in curvilinear form or amoeba-shaped designed through digital modeling in CATIA or 3D MAX software. (Waters 2003)

Free University's library by Norman Foster, constructed in 2005 (Figure 19), is closely akin to Fuller's dome in respect of transparent skin in the shape of
a dome. Constructing such skin aims at suggesting a new notion of architecture in terms of artificially controlling indoor space. At the same time, its large curvilinear span structure made of metal and glass is utterly different from traditional architectural structures composed of vertical walls and a roof. This building’s futuristic exterior especially stands out among other modernism buildings on the campus.

From high-tech architecture to blob architecture, any architecture with futuristic forms ultimately required digital technologies as the most critical tool for actualizing their ideas and design. The development of NURBS-based modeling techniques highly contributed to the fulfillment of this architectural style; moreover, some architects such as Frank Gehry, Zaha Hadid, or Norman Foster voluntarily developed their own “digital design” tools or software suitable for their distinctive design style. (Figure 20)

In the 2010s, however, these curvilinear buildings could neither be perceived as an innovative surprise nor provide a prospective outlook as before, and it was rather regarded as a fixed style of certain architects or criticized for lingering over only morphological experiments. With regard to this criticism, Patrik Schumacher suggested the second version of his own term “Parametricism” by introducing “Parametricism 2.0.” In addition to controlling forms through parameters, Parametricism 2.0 embraces more functional, environmental, and social factors in the process of parametric design. (Frazer 2016)
Meanwhile, distinctive architectural forms realized through free manipulation of forms by computer modeling are construed as a certain type of “ornaments” by Picon (2016). According to him, the formative philosophy of such architects as Zaha Hadid is similar to that of Baroque or Mannerist rather than Renaissance as it prefers instant delight to aesthetics.

5. Conclusion

This study explores the three flows of ideas related to digital technologies within the field of architecture under three orientations: “Mathematics and Function,” “Nature and Structure,” and “Imagination and Form.” The historical origin of these ideologies had its beginning around the 1960s when computers were recently invented. With the proliferation of machines, practical actualization attempts were carried out with vigor. After the 2010s, digital technologies have gained ground as a means of design methodology with the concept of form-finding.

The first flow was focused on the optimization of architecture’s functional parts by quantifying the design process through analyzing requirements and utilizing formulas. Its recent direction is combined with big data or artificial intelligence technologies to actualize more efficient automation of architectural design. The second flow was to find structurally optimized form in nature and design architecture by applying corresponding observations. This methodology aims to find “form,” which is already proven in nature, not giving “form” designed by an architect’s own intentions. In virtue of structural optimization simulations, which became widely available since the 2010s, this methodology has been progressed into the experiments on the architectural form according to characteristics of materials. The third flow pursued inspiration and imagination made feasible by technological development and created the unconventional and futuristic architectural form utterly different from the past. This flow once established itself as the primary current that almost considered equivalent to “digital design”, but compared to the previous two flows, its contribution at this moment is not very remarkable, being sustained by only a few star architects’ styles.

Such categorization of the flows of ideas acquires significance as a framework for comprehensive analysis of disparate features shown in each case or style of an architect. For instance, Norman Foster’s
early works from 1970 to the 1990s reflect the influence of the third flow with the strong representation of concepts such as blob and shell; however, after the 2010s, the second flow, that is form-finding, has been more prominent in his works. Meanwhile, within the second flow, Frank Gehry and Zaha Hadid are exemplary architects who have established their characteristic styles. The second and third flows are intertwined among works of various architects in compliance with time and social conditions, but the first flow tends to be more separately retained by scholars in academia, especially Cambridge in England and MIT in the United States, and corporate design offices. The reason behind this difference lies in the ultimate aim of the first flow, which was “design autonomation,” excluding the traditional role of architects so that its stance differed from that of the second and third flows.

What is also apparent with these three flows is that the role of digital technologies has not been a mere tool for the actualization of architects’ ideas and design. Rather, they have been firmly establishing their position as a design methodology having its own potentials. Accordingly, the term “digital design” has become complex and multifaceted. This testifies that this dynamic term has been used in various ways across theory and practice in the field of architecture. Throughout its history, various meanings and interpretations have been layered and overturned sometimes. This study’s approach to interpreting “digital design” is similar to that of Adrian Forty in his book Words and Buildings, which attempts to explain the various, comprehensive, and sometimes too complex connotations

Figure 17. United States Pavilion, Expo 67 designed by Buckminster Fuller (photo from Estate of R. Buckminster Fuller).

Figure 18. (above) Centre one of Ron Herron’s “insect-like” walking cities, 1964. (photo from Herron archive) (below) Spacelab Cook-Fournier, Kunsthaus (Jencks 2011).

Figure 19. Free University library designed by Norman Foster (photo from Foster+Partners).
of words frequently used in the field of architecture. In other words, this study is valuable in that it categorized the interpretation of “digital design” in three types and deals with the historical development of each flow of ideas beyond the existing perspectives – either peripheral or fragmented – in the history and theory of post-modern or contemporary architecture. Moreover, it established a framework for the further in-depth and heterogeneous interpretation of how digital technology has influenced contemporary architecture.

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Figure 20. Wangjing SOHO designed by Zaha Hadid (photo from ZHA).
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