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Analysis of Form and Space Changes in Design Process of Free-form Architecture of Culture-Related Facilities in South Korea

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Abstract This research investigates the design process of free-form architecture to understand the design strategy and changing factors during the development phase and the cause for them. It is aimed to foresee the changing factors from the design process and to reduce design changes. It analyzes the design changes of free-form architecture based on projects with finalized documentation or under construction in South Korea. Many free-form shapes of the free-form architectures have to be adjusted to rigid-form in order to satisfy function and be economical to build. The research finds three patterns in design changes. First, from the factors for design changes: function, constructability, design, program add/subtract, efficiency, circulation; Function and Constructability are the higher factors compared with the rest. The two are the design changes suitable for actual usage and cost savings. Second, each project has different predominant factors for design changes as the degree of free-form is different. Contrary to initial expectation, the greater the degrees of free-form of the competition scheme, the higher the rate of Function among the factors for design changes. Constructability is higher when the degree of the free-form is less than others. It means that the lower the degree of the free-form, the more properly planned the space of the building is. Last, Constructability of free-form architecture is considered during the earlier design phase than definite-form, one by which the design changes by comparing 'Before fixed Space Program' (BSP) and 'After fixed Space Program' (ASP) design changes. The research would be helpful as a reference for setting up competition guidelines to reduce trial and error during the design process.

Keywords: Free-form, Irregular design, Design process, Architectural Planning, Design change

1. INTRODUCTION

The paradigm of design methodology in contemporary architecture practice has evolved from an analog approach to a digital process on a basis of digital paradigm, with the aid of digital tools. Architecture built on the foundation of the latter often present a free-form shape. The Bilbao Guggenheim Museum in Spain by Frank O. Gehry is one of the most representative building examples in this case. The city of Bilbao, once an economically declining industrial city, has become a successful tourist destination indebted to the introduction of unique free-form architecture.

Projects such as the Dongdaemun Design Plaza or Busan Cinema Complex fall in to the category of global trend of free-form architecture, distinguished from monotonous building types in Korea. Both projects are also clearly aimed to revitalize the urban situation using free-form architecture.

For the design process of typical building types, the overall spatial planning and structural system could be planned at the early design stage by an architect's intuitive idea. After then, the structural system and the details initially planned by an architect are developed through the collaboration with a structural engineer. In case of free-form building, on the contrary, there is a limitation on understanding the efficiency of space inside and the method of construction at the early design stage, because of its experimental nature. Thus, spatial efficiency is reviewed later at the design development phase, which brings the high probability of changing the space designed initially.

Although a few free-form related researches have been done recently, most of them are focused on the design concept and diagram, or on the construction methodology. However, there have not been a sufficient number of studies on the design process, which lies between the design concept and the construction methodology (Wong, 2010).

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This research is aimed to analyze the factors for design changes in the design process and to examine the influence of each factor in free-form architecture of culture-related facilities in South Korea. The factors for design changes are derived based on the analysis of the characteristics of free-form design process, and also on the review from the experts related to the projects. The factors for design changes are examined by the projects, and additionally by each design stage. It is aimed to foresee the changing factors from the design process and to reduce design changes.

2. RESEARCH TRENDS ON FREE-FORM ARCHITECTURAL DESIGN

Table 1. Recent related researches

	Author	Title
Design & Computer program	Jung-Dae Park (2005)	A study on digital technology for the construction of curved forms
	Rivka Oxman (2008)	Digital architecture as a challenge for design pedagogy
	İpek Gürsel Dino (2012)	Creative design exploration by parametric generative systems in architecture
Construction Technology	Helmut Pottmann (2007)	Geometry of multi-layer free-form structures for architecture
	Helmut Pottmann (2008)	Free-form surfaces from single curved panels
	Michael Eigensatz (2010)	Paneling architectural free-form surfaces
	Ji-Yeon Han (2013)	A study on the classification and its features of fabrication types in realizing double-curved surface of free-form architecture

Free-form architecture around the world has recently become a barometer for the level of technology, culture and the economy of the country. The research conducted during the early stage of free-form architecture practice have mostly focused on the creation of form or the developing tool due to its experimental nature and the lack of technology.

The studies on the form-generation are opening up a new direction for contemporary architecture. The recent rapid development of digital technology has allowed the realizations of many free-form architectures, and thus, there is an urgent need to discuss the topics regarding actual construction as well as form-generation. The studies on construction technology, however, focused only on the technical aspects of realizing curved form, and all of 4 previous researches on construction focused on curved panels. It is necessary to discuss more on the economics of the design process and the mechanism of negotiating spatial condition based on a function.

The researches related to free-form architecture shows that the terms such as digital, informal, and irregular are used along with free-form, and that there has not been a clear definition regarding free-form architecture. However, each paper could be categorized into the following subjects: the formation of irregular spatial condition by digital methodology, the creation of space with varied curves, and the experiments on the building envelope materials to achieve these curves. Among these diverse topics, this paper is focused on the building of architecture with varied curves and without systematic formal rule (Table 1).

3. DEFINITION AND CHARACTERS OF FREE-FORM ARCHITECTURE

The term 'free-form' indicates a shape of free-flowing, flexible and topological form (Park, 2005). In the early phase when the imagination and the conception of architects surpassed the technology of the time by far, free-form architecture was rather understood as visionary architecture described only in a media of drawings, images, models and the text.

The complex shapes of free-form architecture are difficult to understand without the aid of a digital tool. First, the irregular exterior curves are difficult to measure precisely without an aid of digital media. Second, the interior space of free-form building also has a non-Euclidean geometry volume, which makes it hard to plan the interior space properly. Lastly, free-form buildings generally have a dual structural system - a primary structure system for supporting overall building loads and a secondary one for building skin. This complicated and bulky structural system changes the interior space different from the architect's original intention. In general, free-form architecture has to go through a lot more trial and error iterations compared to the design process of typical definite-form architecture (Gausa, 2003).

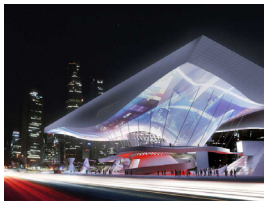
4. FREE-FORM ARCHITECTURE IN SOUTH KOREA

During the first decade since the mid 80s, those related to the field of free-form - (architect, 3d renderer, etc.) - concentrated on form-generation. Afterward, various advanced digital media were widely employed for expanding its capacity into the construction field. The Guggenheim Museum in Bilbao, Spain, 1997 designed by Frank O. Gehry was the momentum in which cities all around the world witnessed the enormous effect of the single free-form architecture (Park, 2005).

Table 2. Representative free-form architecture in South Korea

Incheon International Airport Transportation Center

Construction : 2001
Competition : 1995
Floor Area : 76,364m2
Total Cost : unknown



Busan Cinema Complex

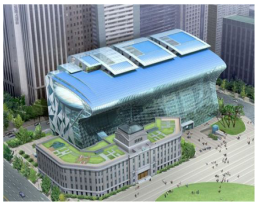
Construction : 2011
Competition : 2005
Floor Area: 54,335m2
Total Cost: KRW 167.8 billion

Floating Island

Construction : 2011
Competition : 2007
Floor Area : 9,629m2
Total Cost : KRW 140.0 billion

Thematic Pavilion of Expo 2012

Construction : 2012
Competition : 2009
Floor Area : 7,413 m2
Total Cost : KRW 57.5 billion



Seoul Metropolitan Civic Hall

Construction : 2012
Competition : 2005
Floor Area : 72,450m2
Total Cost : KRW 298.9 billion

Dongdaemun Design Plaza

Construction : 2014
Competition : 2007
Floor Area: 86,574m2
Total Cost : KRW 484.0 billion

Seoul Performing Art Center

Construction : Canceled
Competition : 2009
Floor Area : 99,102m2
Total Cost : KRW 500.0 billion
(estimation)

Note: The cost of construction for Incheon International Airport Transportation Center is difficult to estimate since the construction comprises multiple parts including the civil engineering and the ground connection parts.

Due to high building costs, free-form architecture was non-existent in South Korea until the 1990s. The Incheon International Airport Transport Center (2001) was the first built free-form architecture in South Korea which took 3 years to design. In order to accomplish the extraordinary shape and the huge column-less space inside, CATIA (a multi-platform CAD/CAM/CAE commercial software suite) was introduced during the design phase. Despite considerable cost for realization, the first real free-form landmark built in South Korea gave fresh impact to its citizens. Since then, there has been more free-form architecture built during the 1990s. Contrary to original intent, most of them have been altered from their original ideas to quasi-free-form shapes during the design and construction phases because of the practicality issues and constructability. Since 2005, free-form buildings have been designed, including the Busan Cinema Complex (2011), the Floating Island (2011), the Thematic Pavilion of Expo 2012 (2012), the Seoul Metropolitan Civic Hall (2012), the Dongdaemun Design Plaza (2014) and the Seoul Performing Art Center (Canceled). Beside the Seoul Performing Art Center, these free-form buildings have been realized including the Dongdaemun Design Plaza which was completed recently.

All of these projects are public landmarks, and their design were selected through international design competitions from which the above projects took at least 2-3 years to design (from competition to construction documentation). However, due to the nature of competition, the participants easily exaggerated their proposal in terms of its shape or spatial condition. This caused unrealistic and inefficient schemes which brought the large scope of changes during the design process (Table 2).

5. METHOD

5.1. Target buildings

In this research, originally 7 buildings were selected which are either at the construction document phase or under construction. The Incheon International Airport Transport Center (2001) and the Floating Island (2011) were excluded because they are either too old or too small to analyze properly. Also the Thematic Pavilion of Expo 2012 (2012) and the Seoul Metropolitan Civic Hall (2012) will not be discussed in this paper since either they are a temporary structure or the application of free-form technology are limited partially to the façade.

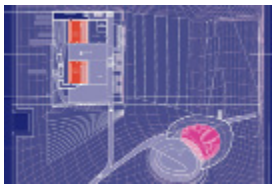
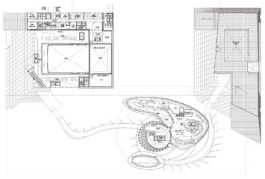
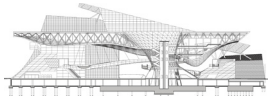
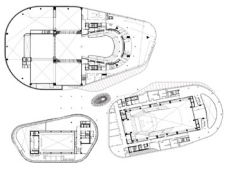
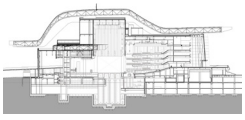
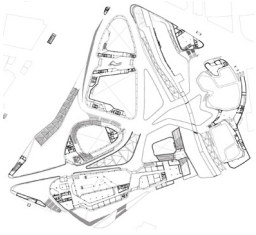
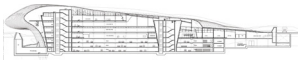
5.2. Method of analysis

For the 3 selected projects, the overall degree of free-form from the competition scheme phase to the construction document phase was examined first (Table 3). Afterwards, design changes were reviewed by six experts including architects and engineers who had worked on the projects, and the common criteria for design change in free-form architecture were derived from the result of the review. Then, the design changes of each project were sorted based on these criteria (Table 4). Since the selected projects have different total floor area, the value of factors applied to the projects is differentiated: the ratio of changed program area per total floor area. In addition, the relationship between the complexity of free-form and factors causing the design change was analyzed. Also, the factors for design changes are further examined in two groups–whether the programs were fixed before the competition or after the competition.

5.3. Factors for free-form design changes

The number of free-form architecture across the world and of the related researches are insufficient presently; it is difficult, therefore, to define the factors of design change in free-form architectures. In this study, the factors for design change in free-form architecture are derived based on the design factors proposed in AIA handbook (The AIA, 2007), and later modified through the review of projects with six experts including architects and engineers who had been working on the projects.

Table 3. Overall degree of free-form during and after design process

		Design competition		Construction documents	
Cinema Complex	Plan		Mass : Definite-form +Free-form Interior Space: Definite-form		Mass : Definite-form +Free-form Interior Space: Definite-form
	Section		Mass : Free-form Interior Space: Definite-form		Mass : Free-form Interior Space: Definite-form
Art Center	Plan		Mass : Free-form Interior Space: Free-form		Mass : Free-form Interior Space: Definite-form
	Section		Mass : Definite-form Roof: Free-form		Mass : Definite-form Roof: Free-form
Design Plaza	Plan		Mass : Free-form Interior Space: Free-form		Mass : Free-form Interior Space: Definite-form
	Section		Mass : Free-form Interior Space: Free-form		Mass : Free-form Interior Space: Definite-form

The 10 factors suggested in AIA handbook are as follows: community concerns, codes and regulations, context and climate, site, schedule, program, client, building technology, sustainability and cost. Among these factors, Community concerns, Codes and regulations, Context and climate, Site and Schedule are excluded from this research since they are mostly influential at the schematic design phase, not the design development phase on which this research is more focused.

Among other five factors, Program is defined as Function and Circulation which will be added or changed to support the program. Client is defined as Program Add/Subtract which client's requirement will bring. The Building technology is defined as Constructability since the materialization of curvature in free-form architecture often causes the change in design. Sustainability is originally described as 'functioning into the future', and is defined as Efficiency since the design change in free-form architecture lies often on the spatial efficiency. The Cost is originally described as 'influence subsequent design decisions', and is defined as Design since the cost in free-form architecture tends to influence the design change more heavily than typical building types. Therefore, in this study, the following is defined as factors for design change in free-form architecture: Function, Circulation, Constructability, Program Add/Subtract, Efficiency and Design.

6. FINDINGS AND DISCUSSION

6.1. Preliminary investigation on the overall degree of free-form on each project

Once identifying the same design phases for comparing projects, the overall degree of free-form from the competition scheme to the final construction document of each project was examined (Table 3).

The Busan Cinema Complex ("Cinema Complex") and the Seoul Performing Art Center ("Art Center") had gone through the idea competition phase, which the Dongdaemun Design Plaza ("Design Plaza") did not. As the Design Plaza was a design competition without any preliminary idea competition, the programs had to be changed afterwards. Because of this, the schematic design phase of the Dongdaemun Design Plaza had to be eliminated. Some of the initial forms of the three projects had to change as they

Table 4. Factors for design changes

Case	Design change	Area (m^2)	Value	Before fixed Space Program						After fixed Space Program					
				P	F	D	C	E	Ci	P	F	D	C	E	Ci
Cinema Complex (54,335m^2)	Office building: plan changed to free-form	1,750	0.032				●	●							
	Addition of a floor in the office building	1,489	0.027	●				●							
	Double corn: 3D shape changed	2,013	0.037		●		●		●						
	Double corn ramp: 3D shape changed	1,405	0.026				●		●						
	Outdoor performing area: 3D shape changed	2,866	0.053		●										
	Movie theater: shape changed	30,000	0.552	●	●		●								
	Restaurant: 3D shape changed	6,146	0.113	●											
	Movie theater: curved corner changed to rectangular one	1,507	0.028								●		●	●	
	Office building: section changed to rectangular-form	3,022	0.057							●			●		
	Restaurant: ramp deleted and spatial division changed.	652	0.228								●				
	Restaurant: ramp changed into the stairs	234	0.004								●	●			
	Performing art theater: ramp changed to escalator	257	0.005												●
Art Center (99,102m^2)	Traffic plaza: 3D shape changed	653	0.007	●			●								
	Opera house, B1: 3D shape changed	3,188	0.032	●	●										
	Symphony hall, 1F: 3D shape changed	4,033	0.041	●											
	Symphony hall, 1F: interior space changed	4,033	0.041	●											
	Cultural facility: 3D shape changed	361	0.004	●					●						
	Symphony hall, 2F: interior space changed	653	0.007		●										
	Experimental box and symphony hall, 4F: volume separated	5,904	0.060	●	●										
	Symphony hall, B1: 3D shape changed	1,041	0.011	●		●									
	Symphony hall: foyer and its staircase added	466	0.005		●										
	Parking facility, B2: 3D shape changed	6,990	0.071		●		●								
	Parking facility: stairwell 3D shape changed	92	0.001				●								
	Composite art facility: core 3D shape changed	114	0.001		●		●								
	Experimental box: 3D shape changed	1,934	0.020		●	●									
	Experimental box: staircase 3D shape changed	78	0.001				●		●						
	Opera house, underground parking: parking ramp and core changed	495	0.005		●										
	Staff cafeteria: entrance hall 3D shape changed	917	0.009		●										
	Deck bridge: a fan shape of sunken space changed	839	0.009		●		●		●						
	Symphony hall, rooftop: deck area 3D shape changed	3,400	0.034		●										
	Symphony hall, B1: 3D shape partially changed	219	0.002								●				
	Experimental box, 1F: parking ramp 3D shape changed	254	0.003								●				
	Experimental box: 3D shape changed	378	0.004								●				
	Experimental box, 2F: wall shape partially changed	36	0.001								●				
	Experimental box, 3F: interior space changed	216	0.002								●				
	Experimental box, B1: core design changed	280	0.003									●			
	Symphony hall: 3D foyer design changed	409	0.004									●			
	Symphony hall, 2F: entrance area changed	369	0.004									●			
	Symphony hall, 3F: 3D shape partially changed	361	0.004									●		●	
	Sound bridge: staircase shape and circulation changed	687	0.007									●			●
	Symphony hall: corner curvature of the shape changed	291	0.003										●		
	Music street: vertical circulation and 3D shape changed	79	0.001								●	●			

Table 4. Factors for design changes (Continued)

Case	Design change	Area (m^2)	Value	Before fixed Space Program						After fixed Space Program					
				P	F	D	C	E	Ci	P	F	D	C	E	Ci
Design Plaza (86,574m^2)	Convention hall: overall 3D shape changed	20,214	0.234	●	●										
	Exhibition hall: overall 3D shape changed	9,304	0.108	●	●										
	Design center: overall 3D shape changed	5,708	0.066	●	●										
	Convention hall 1 and 2, 1F: in-between space changed to lobby	2,659	0.031	●	●			●	●						
	Convention hall and Exhibition hall, 1F: in-between space changed to loading deck	2,477	0.029	●				●							
	Design center, 1F: in-between space changed to lobby	295	0.003	●				●							
	Incidental facilities: 3D shape changed	2,040	0.024	●		●		●							
	Storage and machine room, B1: 3D shape changed	5,057	0.058		●										
	Convention hall, 1F: interior space changed	4,306	0.050		●										
	Exhibition hall, 1F: space for support facilities changed	769	0.009		●										
	Design center, 1F: space for browsing room changed	526	0.006		●										
	Design center, 1F: space for shops and cafe changed	58	0.001		●										
	Design center, 1F: space for study room changed	206	0.002		●										
	Design center, 1F: space for lecture and seminar changed	272	0.003		●										
	Design center, 2F: space for design shop changed	592	0.007		●										
	Design center, 2F: space for office changed	2,946	0.034		●										
	Design center, 2F: space for convenient facilities changed	1,175	0.014		●										
	Design center, 2F: terrace shape changed	3,143	0.036		●										
	Convention hall, 2F: space for support facilities changed	1,379	0.016	●	●										
	Design center, 2F: staircase for browsing room changed	320	0.004			●									
	Exhibition hall: ramp changed to escalator	341	0.004						●						
	Incidental facilities: location and 3D shape changed	2,253	0.026									●			
	Storage and machine room, B1: enlarged and 3D shape changed	6,385	0.074								●			●	
	Parking ramp, B1: 3D shape changed	566	0.007								●				
	Exhibition hall: staircase shape changed	357	0.004									●			
	Exhibition hall: outside circulation simplified	645	0.008								●				●
	Exhibition hall, 1F: corridor space changed	677	0.008								●				

P: Program Add/Subtract, F: Function, D: Design, C: Constructability, E: Efficiency, Ci: Circulation

had gone through the different design process. Some even lost their free-form characters. Plans and sections were useful to find out those design changes while 3D were used as complements.

The competition design of the Cinema Complex consists of two volumes. One is free-form and the other is non free-form in plan. Both volumes looked free-form like in section although interior spaces are typical rectilinear

shape. The final design kept the original free-form character of the Cinema Complex, while adding more emphasis to the final outcome.

Plans for the initial competition proposal of the Art Center showed free-form shapes both exterior and interior. The final construction document showed that the exterior was still the free-form shape while interior space had been changed into typical rectangular performing hall for the efficiency. The overall sections of the Art Center were also typical rectangular shapes except for the roof.

The initial competition schemes of the Design Plaza are free-form both in plans and sections. The final construction documents kept the shapes except the interior space where typical rectangular plans and sections are found.

6.2. Analysis of factors for design change in free-form architecture

The factors for design change in free-form architecture (Table 4) could be sorted into 6 criteria as shown in Table 5: program, add/subtract, function, efficiency, design, constructability and circulation. Although the difficulty of constructing free-form shapes or the reduction of construction costs was expected to be the greatest reason for a design change, Function is the most

accountable factor among others with a rate of 48.19%. Below is an explanation of each factor.

(1) Function

Function refers to the change of shape based on the functional need of space, and is the biggest reason for a design change in free-form architecture. Since the major consideration often lies on the shape in the design competition phase, many parts of interior and exterior spaces are developed on a free-form basis, which may include a spatial condition inconvenient to an actual user. Therefore, in many cases, these free-form buildings have to change their shape to gain better efficiency depending on the programs (Figure 1).

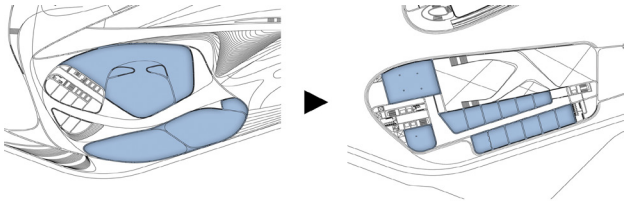


Figure 1. Design Plaza

(2) Program Add/Subtract

The next biggest factor for design change is Program Add/Subtract with a rate of 29.43%. In most cases, the required program list was not fixed at the competition phase, which brings the design change by client's request thereafter. Since the proposed volume from design competition phase could not allow the supporting facilities to be added later, the size of the building was readjusted and the stream lined form was rationalized in many cases (Figure 2). For example, the size of the Design Plaza was changed from three levels including one underground level at the design competition phase to eight levels including four underground levels at the schematic design stage.

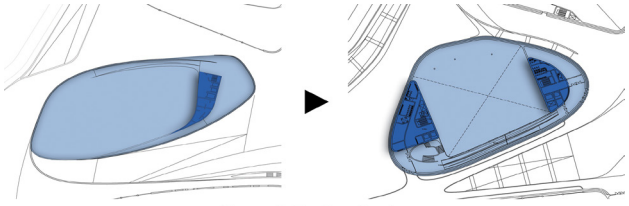


Figure 2. Design Plaza

(3) Constructability

The third highest factor for design change is Constructability with a rate of 12.63%. In the case of free-form architecture, it is difficult to understand the structural and mechanical system only by reviewing two dimensional drawings. Also, it is likely to have a discrepancy between plan and section. Therefore, 3D computer software such as CATIA is used for building these forms and for examining the size of steel frame. Yet those examinations are done after the competition. Moreover, it is applied for reshaping the surface or for changing the curvature to meet the structural requirements. The curvature of form is particularly related to the exterior panel and the manufacturing cost for panel, becomes higher as the radius of curvature decreases or the curvature is close to the free-curved line. Thus, to save construction costs, either free-curved line is simplified or the curved surface is flattened (Figure 3, Figure 4).

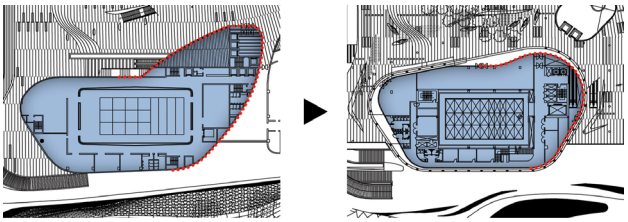


Figure 3. Art Center

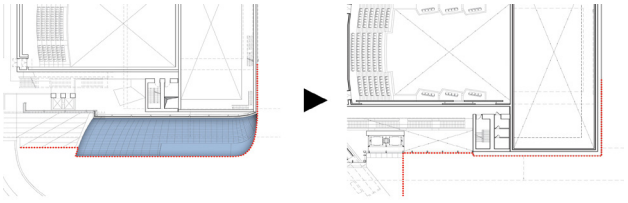


Figure 4. Cinema Complex

(4) Efficiency

Efficiency refers to the utilization of space, different from Function which adjusts the original space plan to the actual usage. It refers to the change of design or programs to turn a dead space of free-form mass into an accessible space. As many rooms planned at the design competition phase were not actually accessible, these dead spaces were rationalized at the SD phase. For example, there was no special plan for the inter-space between conventions 1 and 2 of the Design Plaza, but it turned into the lobby and information space by introducing an entrance accessible from the first level during the SD phase (Figure 5). In addition, some dead spaces were converted into the loading zone or used as a space for connecting ramp from the first basement level to the ground floor.

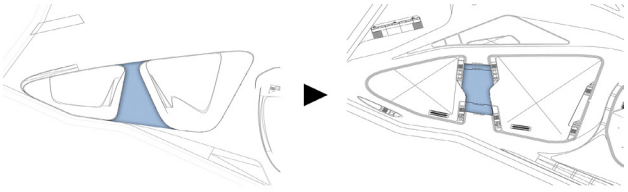


Figure 5. Design Plaza

Table 5. Distribution ratio of factors for design change

Program Add/Subtract	Function	Design	Constructability	Efficiency	Circulation	Total
0.719(29.43%)	1.178(48.19%)	0.075(3.08%)	0.309(12.63%)	0.109(4.47%)	0.054(2.20%)	2.444(100%)

(5) Design

The particular shape requires consideration from the user perspective and for its feasibility. The design of the shape, however, could be regarded as the main purpose for free-form architecture practice, and therefore, the building is developed to emphasize the shape. We call it 'Design'. The rate of Design is 3.08%, close to that of Constructability. As shown below, the change of design occurred partially to the shape of staircase and ramp, not to the general design concept (Figure 6).

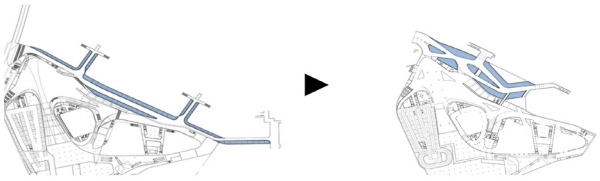


Figure 6. Design Plaza

(6) Circulation

Lastly, Circulation includes a plan for supplementary vertical circulation. In addition to the existing ramp, more elevators were planned as the size of building had expanded due to the additional supporting facilities introduced at the later stage (Figure 7). Also in some cases, the free-form shaped ramp was substituted with an elevator for user's convenience (Figure 8).

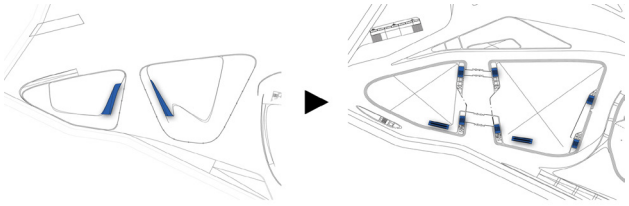


Figure 7. Design Plaza

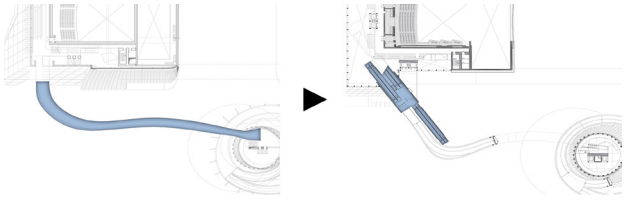


Figure 8. Cinema Complex

6.3 The comparison of factors for design change among selected projects

Table 6 shows the comparison of factors for design change among selected projects. Function, one of the factors for design, stands out as an important factor throughout all cases. The Design Plaza especially shows the largest rate in Function, because interior space division as well as exterior form has a free-form shape both in plan and section. Each project has different predominant factors for design changes as the degree of free-form is different. Contrary to initial expectation, the greater the degree of free-form on the competition scheme, the higher the rate of Function among the factors for design changes is. The rate of Constructability is higher when the degree of the free-form is less than others. In other words, the lesser that free-form is applied to a project, the more properly planned the space for the project becomes.

Function accounts for 57.29% in the Design Plaza, and it involves the change based on the functional scope of the room. As mentioned in 6.1, free-form interior spatial division of initial stage has tended to be changed to a configuration of a definite-form as the design process develops. In case of the Design Plaza, it was expected that the rate of change by Constructability would be great due to its high degree of free-form, but it turned out to be low since the BIM was applied to integrate the design and construction.

In case of the Art Center, except for Function, the main reason of design change is Program Add/Subtract and Constructability. Because the Art Center, unlike other projects, has programs requiring specific function such as the opera house and symphony hall, and the client's requirement on these programs brought further changes through the development phase. Similar to the Design Plaza, the initial design of the Art Center has a free-form exterior and interior, although not up to the degree of Design Plaza. The change by Constructability includes the area in which a free curved line is readjusted to a linear condition, or the area of which spatial division is rearranged on the basis of structural analysis.

The rate of Constructability, compared to other projects, took a greater part in design change for the Cinema Complex. Because the double-cone area, a free-form part of the project, caused increase of construction costs, most of the design changes were aimed to reduce it.

Table 6. Factors for design changes on selected free-form architecture

Case	Program Add/Subtract	Function	Design	Constructability	Efficiency	Circulation	Total
Design Plaza	0.243	0.494	0.042	0.000	0.068	0.015	0.862
	28.17%	57.29%	4.83%	0.00%	7.93%	1.78%	100%
Art Center	0.138	0.195	0.031	0.046	0.002	0.009	0.421
	32.69%	46.43%	7.45%	10.98%	0.43%	2.02%	100%
Cinema Complex	0.339	0.488	0.002	0.262	0.039	0.030	1.160
	29.18%	42.06%	0.19%	22.62%	3.37%	2.59%	100%

Table 7. Factor of design change by design process

Case	Program Add/Subtract	Function	Design	Constructability	Efficiency	Circulation	Total
BSP	0.691	0.872	0.027	0.269	0.061	0.042	1.962
	35.24%	44.45%	1.35%	13.69%	3.13%	2.14%	100%
ASP	0.028	0.305	0.049	0.040	0.048	0.012	0.482
	5.77%	63.40%	10.10%	8.30%	9.95%	2.47%	100%

6.4 The comparison of factors for design change of each design process

The state of determination of programs differentiates a design process considerably. Thus, factors for design change are expected to be different before and after the finalizations (Table 7). Each case is reviewed based on this criterion: 'Before fixed Space Programs' (BSP) and 'After fixed Space Programs' (ASP).

Function holds the position of the most influential factor for design change both in BSP, 44.45% and ASP, 63.40%. The free-form shape of space has been changed to meet the functional need of the room throughout the whole design process. In terms of total rate of design changes, ASP is higher than BSP.

Except Function, the analysis presents that the rate of Design, Efficiency and Circulation is higher on ASP than BSP; Design especially shows the biggest difference in rate. This includes the part changed in the BSP stage due to the feasibility being readjusted to emphasize on free-form shape and design perspective within the extent of minor impact on construction and efficiency

On the contrary, the analysis presents that the rate of Program Add/Subtract and Constructability is higher on BSP than ASP. The rate of Program Add/Subtract on BSP is 35.24%, while it was 5.77% on ASP. Constructability is mainly readjusting the free curved line to the straight line in order to reduce the number of the exterior curved panels. The rate of Constructability on BSP is higher than on ASP. It means that the Constructability of free-form architecture is considered an earlier phase than a definite-form one.

Overall, in addition to an economic feasibility and space efficiency which are the key factors for developing a design in the BSP phase, Design -the major property of free-form architecture- appears to be the major factor for the design process in the ASP phase.

7. CONCLUSION

Once the free-form designs were selected from competitions, the winning schemes had to go through numerous design changes because their competition schemes tended to be unrealistic and inefficient. A lot of free-form shapes had to be adjusted to definite-form in order to satisfy function and be economical to build.

Among the factors for design changes (Function, Program Add/Subtract, Efficiency, Design, Circulation), Function and Program Add/Subtract are the higher factors compared to the rest. They are the most suitable design changes for actual usage and cost saving. There were a few design changes which have even more emphasized its free-form for their iconic values. In addition, there were many design changes to meet the client's requirements as they became specified from the competition stage.

Each project has different predominant factors for design changes as the degree of free-form is different. Contrary to initial expectation, the greater the degree of free-form on the competition scheme, the higher the rate of Function among the factors for design changes. The rate of Constructability is higher when the degree of the free-form is less than others. It means that the lesser the degree of the free-form is, the more properly planned, the space of the building is. The Cinema Complex, which had definite-form in plan, has a higher rate of Constructability design changes. The Design Plaza of great degree of free form shows lower rate of Constructability by virtue of the early adoption of integrated design such as BIM from the schematic design phase.

Lastly, comparing to the design process of definite form architecture in which the Constructability is considered at ASP generally, it is much earlier in free-form architecture, mostly at BSP.

The construction of free-form architecture generally requires enormous budget and high-end technology. Thus, the number of free-form architecture is small across the world, which brings the limitation of the quantitative analysis. However, this research will be helpful as a reference for setting up competition guidelines, which can reduce trial and error during the design process. For example, a program list in free-form architecture at the development phase is required to be more specific than typical building program list. Since these buildings are under construction phase, a consecutive study to analyze factors for design changes during the construction is necessary.

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