Flood Risk Assessment and Resilience Plan Development of Seoul using multidimensional spatial analysis frameworks: QGIS and Unity 3D

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01 Overview

This study identifies the most flood-vulnerable district in Seoul during flood susceptible period and develops an area-specific resilience plan to minimize its damage. Flood Risk Assessment were conducted in both 2-dimensional and 3-dimensional level with the aid of spatial analysis frameworks – QGIS and Unity 3D – to analyze the flood risk of each district in quantitative and qualitative perspective. By using 23 socioeconomic, geographic and meteorological variables, the most flood-vulnerable district was identified as 'Sinjeong-7-dong' and therefore was selected as the case study area. Based on the result of a 3D virtual flood simulation of Sinjeong-7-dong and the flood risk assessment of Seoul, a flood resilience plan for the case study area can be suggested in 3 aspects; urban facilities management, urban planning, and citizen participation.

02 Background

[Figure 1] Flooded area of Han River park during 2020 monsoon. Due to consecutive typhoons, most of the Han River park was flooded this summer.

Seoul has been considered as a relatively safe city from flood or typhoons so far, compared to other flood-prone cities like New Orleans, Houston, Guangzhou, etc. In fact, there are no Korean cities included in the top 20 most flood-vulnerable cities in the world. Although it is a seemingly relaxing fact, it is undeniable that Seoul is not exempt from climate change and its impact was shown this summer. As [Figure 1] shows the vulnerability of Seoul to flood, it is crucial to identify vulnerable districts in Seoul and develop specific flood resilience plan to minimize its damage.

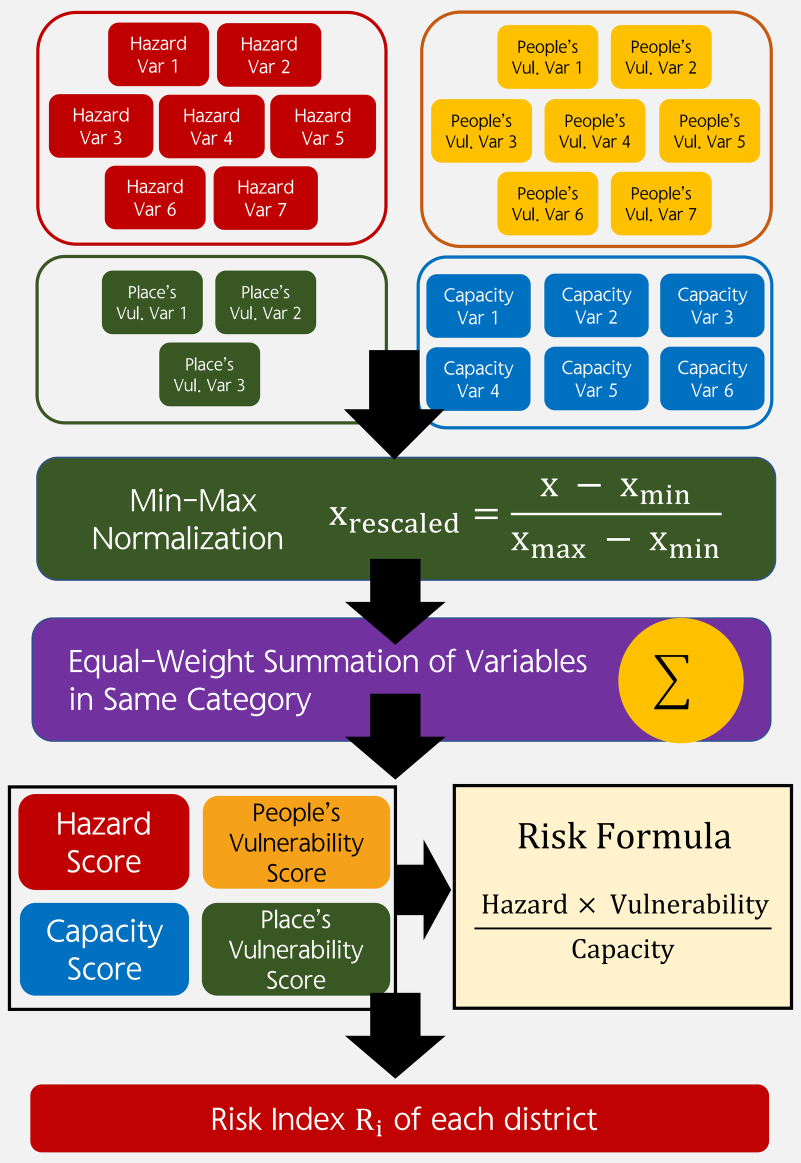
03 Methodology

This study investigates 3 subjects.
(1) Flood Risk Assessment of Seoul
(2) Flood Risk Assessment of Sinjeong-7-dong
(3) Resilience Plan Development for Sinjeong-7-dong

For subject (1), a typical risk assessment method will be used with the aid of a 2D spatial analysis framework – QGIS – to display and analyze its result. For subject (2), on-site study and a 3D virtual flood simulation will be conducted on Sinjeong-7-dong, by using unity 3D to visualize the flood risk of the case study area. Lastly, we will propose a resilience plan for Sinjeong-7-dong based on the results from our flood risk assessment and on-site study.

[Figure 2] Spatial Analysis Frameworks used in this study – QGIS & Unity 3D

04 Analysis



[Figure 3] Diagram of Flood Risk Assessment. The risk index R_i was calculated for every dong in Seoul by following the process described above. For more information about the risk formula, see [Figure 4].

04-1 Risk Assessment of Seoul

[Figure 4] Risk Formula used in Flood Risk Assessment. Note that 1.5 was assigned to w_{haz}, w_{plc}, w_{cap} equally, while while w_{plc} = 1.0. A different weight value assignment may produce a different result.

$$R_i = \frac{(w_{haz} H_i)(w_{ppl} V_{ppl,i} + w_{plc} V_{plc,i})}{w_{cap} C_i}$$

i = Administrative number of the district $(1 \leq i \leq 424,\ i \in N)$

w_{haz} = weight value of hazard score

H_i = hazard score of district i

w_{ppl} = weight value of People's vulnerability score

$V_{ppl,i}$ = People's Vulnerability score of district i

w_{plc} = weight value of Place's vulnerability score

$V_{plc,i}$ = Place's Vulnerability score of district i

w_{cap} = weight value of capacity score

C_i = Capacity score of district i

Flood Risk Assessment of Seoul was conducted in 'dong' level which is the lowest administrative unit of districts in Seoul. By using the risk formula in [Figure 4], the risk index R_i was calculated where I denotes the identification number for 424 dongs in Seoul. Then, the district with the highest risk index score was selected as the case study area for a thorough analysis.

The risk index was calculated by the process shown in [Figure 3]. The risk index aggregates 23 socioeconomic, geographic, and meteorological variables shown in [Table 1]. Since each variables have different units, the score of each variables were standardized by min-max normalization so that the score of each variable were rescaled from 0 to 1. Then, the score of 7 variables were summed for hazard, 10 variables were summed for vulnerability, and 6 variables were summed for computing capacity score. During the summation, the same weight value was applied for each of the variables except for the variables that have similar characteristics like 'Historic Precipitation' and 'Precipitation Forecast'. Those variables were given a weight value of '0.5' while other variables were given a weight value of '1'. The vulnerability index were calculated as a sum of people's vulnerability index and place's vulnerability index in order to analyze the vulnerability of a district in both socioeconomic and spatial perspective.

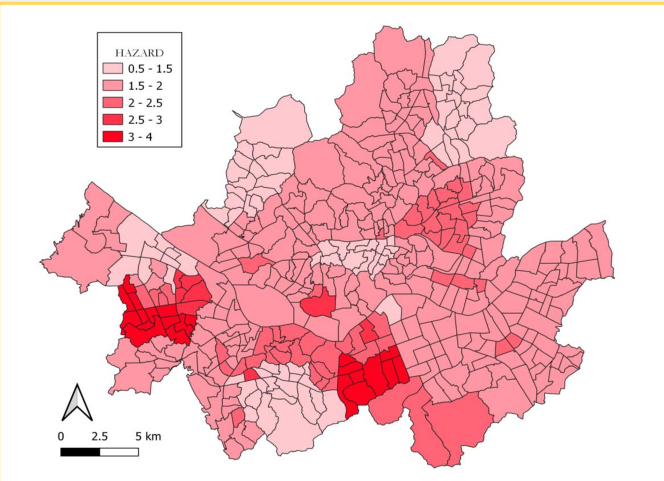
Variables

No	Variable Name	Category	Weight
1	Average Altitude	Hazard	1
2	Impervious Surface Rate	Hazard	1
3	Flood Risk District (Included or Not)	Hazard	1
4	Historical Flood Damage (Economic)	Hazard	1
5	Historical Flooded Area Rate	Hazard	1
6	Historic Precipitation	Hazard	0.5
7	Precipitation Forecast	Hazard	0.5
8	Population Density	People's Vulnerability	1
9	Foreigner Ratio	People's Vulnerability	1
10	15 or below, 65 or above pop ratio	People's Vulnerability	1
11	Sex Ratio	People's Vulnerability	1
12	Average Occupants per Household	People's Vulnerability	1
13	Poverty	People's Vulnerability	1
14	Employment Rate	People's Vulnerability	1
15	Old Buildings Ratio	Place's Vulnerability	1
16	Average House Price	Place's Vulnerability	0.5
17	Average House Rental Cost	Place's Vulnerability	0.5
18	Green Zone Rate	Capacity	1
19	Economic Independency	Capacity	1
20	Number of Public Officials	Capacity	1
21	Gross Regional Domestic Product (GRDP)	Capacity	1
22	Rainwater Pumping Station (Y/N)	Capacity	1
23	Reservoir (Y/N)	Capacity	1

[Table 1] Variables used in Flood Risk Assessment. 23 variables were aggregated to compute the risk index of each district(dong) in Seoul. Since 'Historic Precipitation' and 'Precipitation Forecast' share similar properties, the weight values of those variables are 0.5 in order to balance its effect on risk index with other variables. Likewise, the weight values for 'Average House Price' and 'Average House Rental Cost', are 0.5.

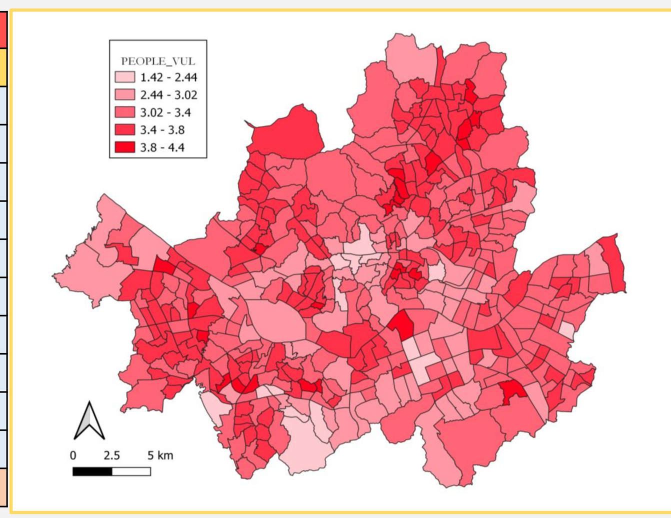
The variables in [Table 1] were fed into a model described in [Figure 3], to compute the risk index of each district. Then, the results were visualized in a 2D map by using QGIS to analyze the result easily. The results are shown below in [Figure 5-9].

Rank	District	Hazard
1	신월1동	3.903509712
2	서초2동	3.888728414
3	신정4동	3.854150784
4	신정2동	3.84456543
5	신월4동	3.713414729
6	신정1동	3.679337505
7	신월2동	3.678623101
8	신정7동	3.593336234
8	신월5동	3.593336234
8	신월6동	3.593336234



[Figure 5] Flood Hazard Map of Seoul. A map showing the hazard score – aggregation of 7 hazard variables – of each district in Seoul. Districts with high hazard score indicates that the district has a high possibility to experience flood during flood susceptible period. Sinwol-1-dong was identified to have the highest hazard score, while Sinjeong-7-dong (case study area) was ranked as 8th place.

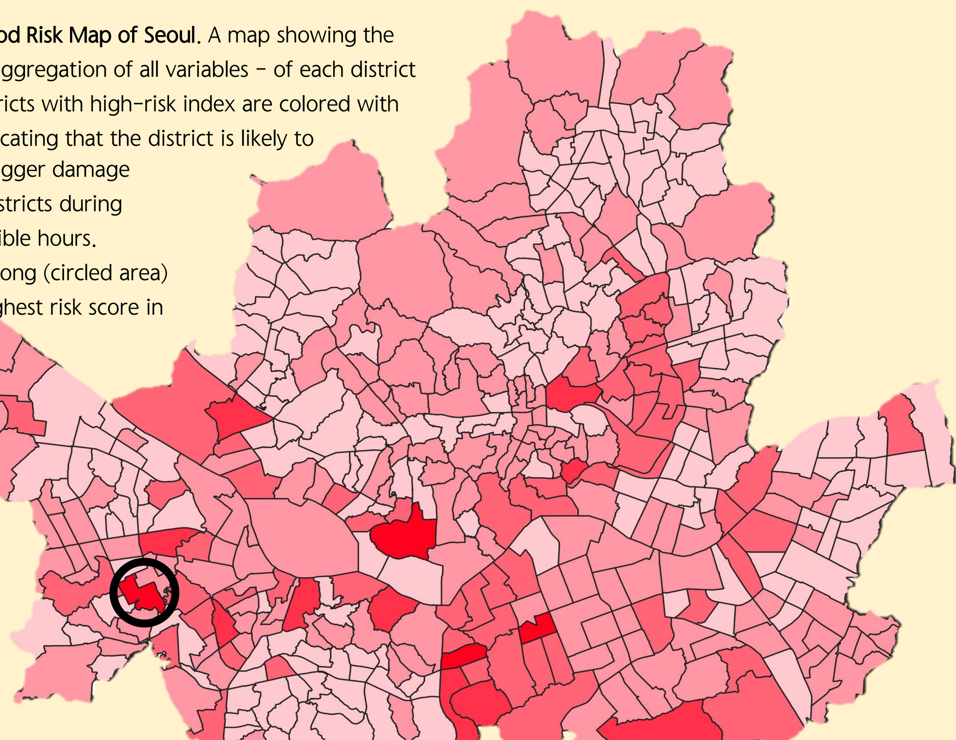
Rank	District	People's Vul.
1	중계2.3동	4.395679
2	삼각산동	4.347525
3	등촌3동	4.292565
4	행당2동	4.291713
5	돈암2동	4.234077
6	길음1동	4.149033
7	하계2동	4.142537
8	중계1동	4.107153
9	구로4동	4.082870
10	청림동	4.070239
…	…	…
58	신정7동	3.671847



[Figure 6] People's Vulnerability Map (Flood) of Seoul. A map showing the People's Vulnerability score – aggregation of 7 people's vulnerability variables – of each district in Seoul. Districts with high people's vulnerability score indicates that the district is more vulnerable to flood and are likely to suffer more loss than other districts. Junggye-2,3-dong was identified as the most vulnerable district in terms of people's vulnerability, while Sinjeong-7-dong (case study area) was ranked as 58th place.

Rank	District	Risk
1	신정7동	47.04005
2	서초4동	43.66626
3	방배4동	43.48465
4	한강로동	40.65747
5	용신동	37.16826
6	성산2동	36.50440
7	대림3동	32.92654
8	내곡동	32.76546
9	응봉동	31.40713
10	방배3동	30.95365
11	대방동	30.47136
12	흑석동	30.27103
13	방배2동	30.20522
14	목1동	30.10788
15	금호4가동	29.86170

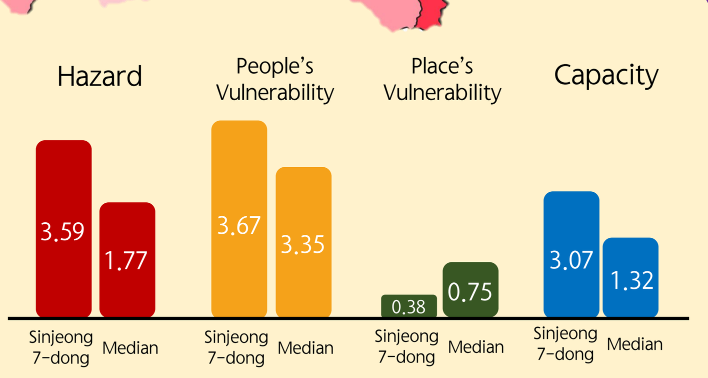
[Figure 9] Flood Risk Map of Seoul. A map showing the Risk index – aggregation of all variables – of each district in Seoul. Districts with high-risk index are colored with dark red, indicating that the district is likely to experience bigger damage than other districts during flood susceptible hours. Sinjeong-7-dong (circled area) shows the highest risk score in Seoul.



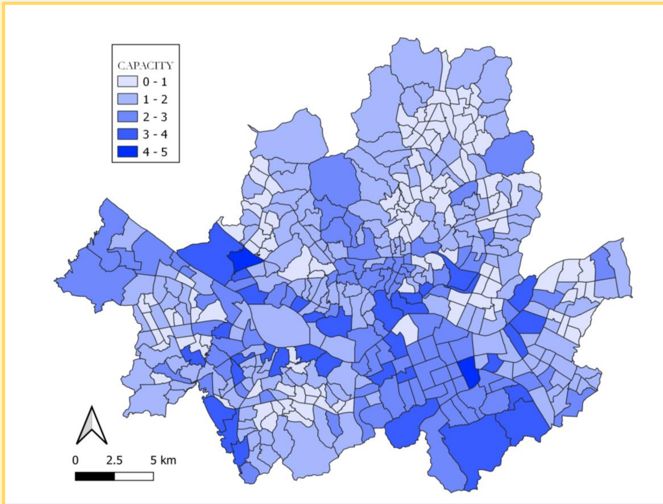
Result Analysis

Sinjeong-7-dong was identified as the district with the highest risk index score. Although the capacity score is higher than the median capacity value (which lowers the risk index score), the hazard and People's vulnerability score is also very high which eventually led to a high risk-score. This implies that resilience plan must be developed for Sinjeong-7-dong in order to reduce its hazard and make 'more' improvements for increasing its capacity.

Therefore, Sinjeong-7-dong was selected as the case study area and assessed as below.

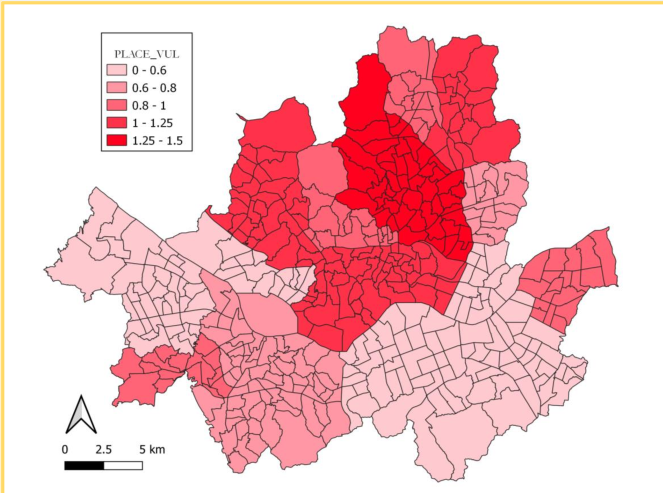


Rank	District	Capacity
1	상계10동	0.358470
2	쌍문3동	0.358504
3	신사동	0.360099
4	중계1동	0.362527
5	창5동	0.400540
6	쌍문2동	0.404105
7	상계8동	0.447233
8	상계2동	0.459978
9	하계2동	0.467365
10	중앙동	0.467764
…	…	…
391	신정7동	3.078126



[Figure 7] Flood Capacity Map of Seoul. A map showing the capacity score – aggregation of 6 capacity variables – of each district in Seoul. Districts with low-capacity score indicates that the district has low capabilities to respond to flood during flood susceptible hours. Sanggye-10-dong was identified to have the lowest capacity, while Sinjeong-7-dong (case study area) shows a relatively high-capacity score.

Rank	District	Place's Vul.
1	답십리1동	1.492156
2	답십리2동	1.492156
3	용신동	1.492156
4	이문1동	1.492156
5	이문2동	1.492156
6	장안1동	1.492156
7	장안2동	1.492156
8	전농1동	1.492156
9	전농2동	1.492156
10	제기동	1.492156
…	…	…
407	신정7동	0.387357



[Figure 8] Place's Vulnerability Map (Flood) of Seoul. A map showing the Place's Vulnerability score – aggregation of 3 place's vulnerability variables – of each district in Seoul. Unlike other categories, the data for place's vulnerability variables were obtained in 'gu' level. Therefore, the same score was given to all dongs in the same gu, which led to a 'gu' level result as shown in the map. Note that the gap between the 1st place and the 407th place is very small compared to other categories, since there are only 3 variables that were aggregated for this category.

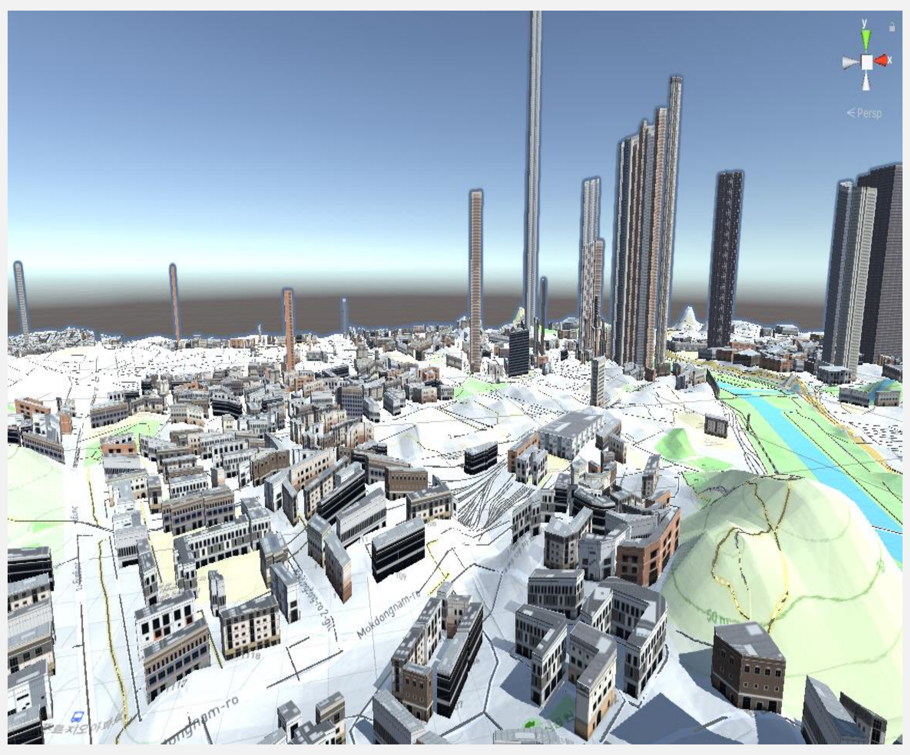
04-2 Risk Assessment of Case Study Area : Sinjeong-7-dong

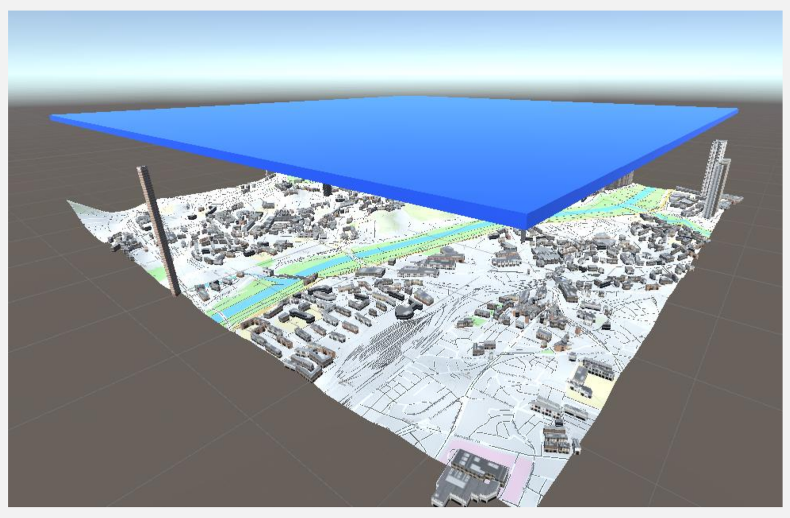
1) 3D Virtual Flood Simulation

For a better understanding of the geographical environment and the flood risk of Sinjeong-7-dong, a 3D virtual flood simulation of Sinjeong-7-dong was conducted by using a software called 'Unity 3D'. Unity 3D allows creating custom 3D maps based on real map and real terrain. By using Mapbox API, we were able to import real world map and terrain, and then create a 3D map of Sinjeong-7-dong based on those data as shown is [Figure 10].

On this map, we have created a flood simulation environment by adding a water layer on top of the 3D map like [Figure 11]. Since Unity 3D does the relevant calculation for dynamics (real world physics) automatically and apply them in the result, we can create a raining environment/weather by adding appropriate amount of water layer on top of the terrain.

In order to visualize the result of a heavy rain or flood, we have calculated the amount of rain that should be poured by referring to the standard of declaring a 'Heavy Rain Warning' in Korea. Also, since unity 3D cannot implement a feature that drains water according to the location and the number of sewers in the district, we have subtracted the amount of water that can be processed in local rainwater pumping station and by pervious surface every hour. i.e. we have only added the net amount of water that won't be processed every hour.

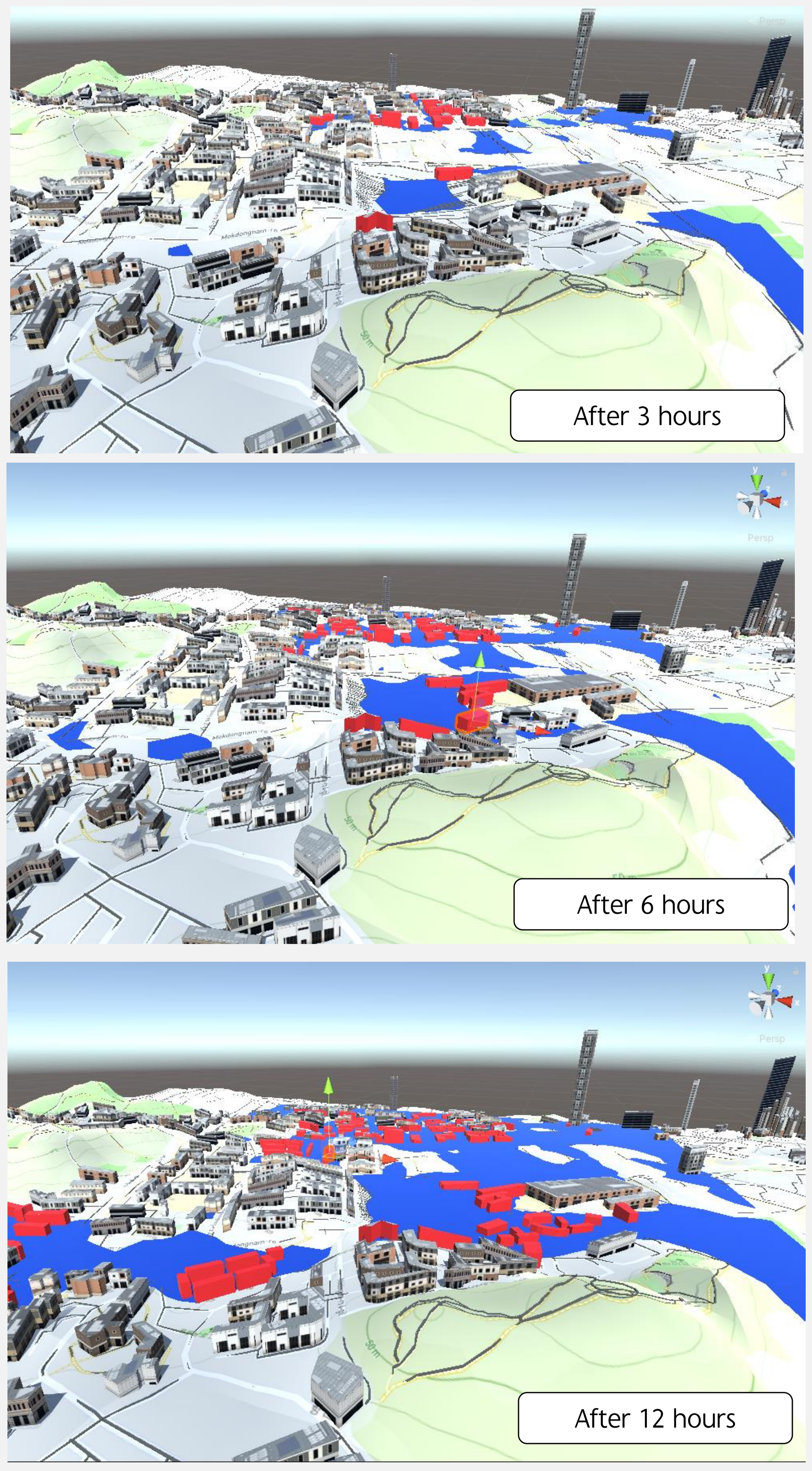




[Figure 11] Adding water layer to real world terrain. Unity 3D performs the relevant calculation for dynamics when an object is added on top of another object, and then shows the result according to it. By using this function, a water layer can be added on top of Sinjeong-7-dong to simulate a heavy rain.

[Figure 10] 3D Map of Sinjeong-7-dong (left). By using Unity 3D and Mapbox API, we have imported real terrain and buildings of Sinjeong-7-dong to build a 3-dimensional map.

3D Simulation Result



[Figure 13] shows the result after a heavy rain with 30mm per hour intensity that lasted for 3 hours, 6 hours, and 12 hours, respectively. (Note that according to Korea Meteorological Administration, 30mm per hour is the standard for declaring a 'Heavy Rain Warning' in Korea) Buildings within the impact zone are colored in red and the number of colored buildings have increased every hour. The formula for calculating the net amount of water that should be poured on top of Sinjeong-7-dong *every hour* in the simulation, is described below in [Figure 12].

Based on the result of the simulation, we were able to identify specific buildings that are in the impact zone in every timestep (3 hours, 6 hours, and 12 hours). Those buildings are more vulnerable than other buildings and are prone to suffer much damage during heavy rain or flood. The impacted buildings tend to be in low altitudes or near the An-yang river, which is a reasonable result. The steep slopes of the terrain caused the rain to flow downwards to low altitude areas, and those areas were easily flooded. Therefore, resilience plan should target for saving those buildings/area.

$$(1) \cdots \text{Amount of Rain} = \text{Precipitation(cm)} \times \text{Area of Sinjeong} - 7 - \text{dong } (cm^2)$$

$$(2) \cdots \text{Pervious Surface Area} = (1 - \text{Imprevious Surface Rate}) \times \text{Area of Sinjeong} - 7 - \text{dong } (cm^2)$$

$$(3) \cdots \text{Amount of Water Absorbed From Pervious Surface} = (2) \times \text{Precipitation (cm)}$$

$$(4) \cdots \text{Water Processing Capacity of Rainwater Pumping Station (1h)} = \text{Total Processing Capacity per hour} \div \text{Number of Responsible Districts}$$

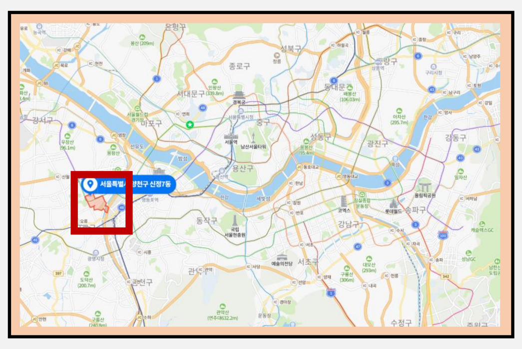
$$\text{Net Amount of Water poured in the simulation (every hour)} = (1) - (3) - (4)$$

[Figure 12] Formula for Calculating Runoff. We have made an equation that approximates the amount of water that is not processed from pervious surface or rainwater pumping station every hour, and therefore should be added on top of the terrain every hour (which is the amount of runoff).

[Figure 13] 3D virtual flood simulation result. Starting from the picture on the top, each picture denotes the result of a heavy rain with 30mm per hour intensity for 3 hours, 6 hours, and 12 hours, respectively. The buildings within the impact zone are colored in red. Impacted buildings are buildings that are relatively more vulnerable than other buildings which will suffer more damage in real flood.

2) On-Site Study

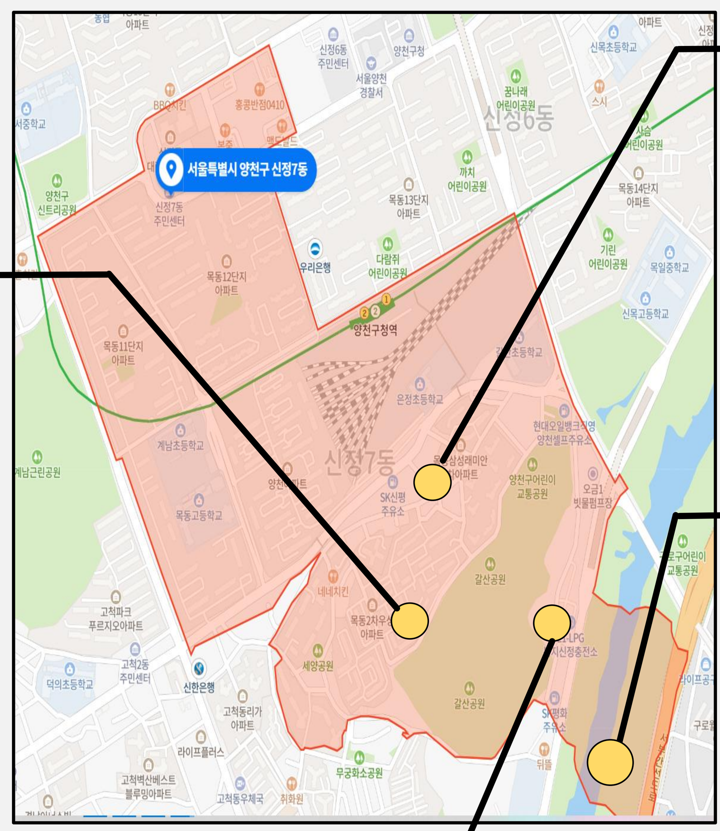
Place : Sinjeong-7-dong
Population : 30,690
Area : 1.74 km^2
Major Facilities : School(5), Senior community center(13), Hospital (1)

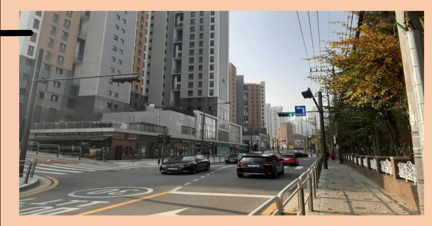


We have also visited our case study area – Sinjeong-7-dong – to assess the flood risk in real world environment. Sinjeong-7-dong is mainly covered with residential area. There are 10,179 apartment houses and 450 conventional houses. In the center, there is a big train station (Line 2, Yangcheon-gu Office station).

We have identified several factors that makes Sinjeong-7-dong vulnerable to flood. Most of the areas have steep slopes and the residential areas were in low land, while parks were in high land. In fact, parks should be located in low land in order to absorb rainwater that comes down from high land. However, the situation in Sinjeong-7-dong was the opposite, which makes excessive amount of rainwater to flow downwards and feed the An-Yang river, eventually making the residential area extremely vulnerable to flood.

Steep Slope
There exists a steep slope between the mountain(park) and the residential area. Since parks are located in high land and residential area is located in low land, this lowers the absorbing capacity of the park(green). More water will flow downward and be cumulated near residential area (than when the parks are located in low land), which makes the residential area to be more vulnerable to flood. Also, due to steep slope, landslide may also occur during flood hours.

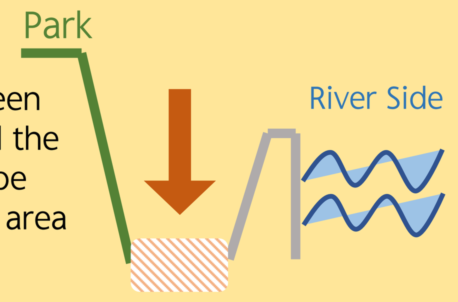




Residential Area
Most of the area in Sinjeong-7-dong is residential area.

An-Yang River
An-Yang river branches from Han river and crosses along Sinjeong-7-dong.

U-type low land
This area is in between high land (park) and the river. This area will be the most vulnerable area to flood.



04-3 Resilience Plan for Case Study Area

Based on the results of our flood risk assessment of Seoul including Sinjeong-7-dong and our findings from on-site study, we have developed a resilience plan for Sinjeong-7-dong in 3 aspects as described in Table 2.

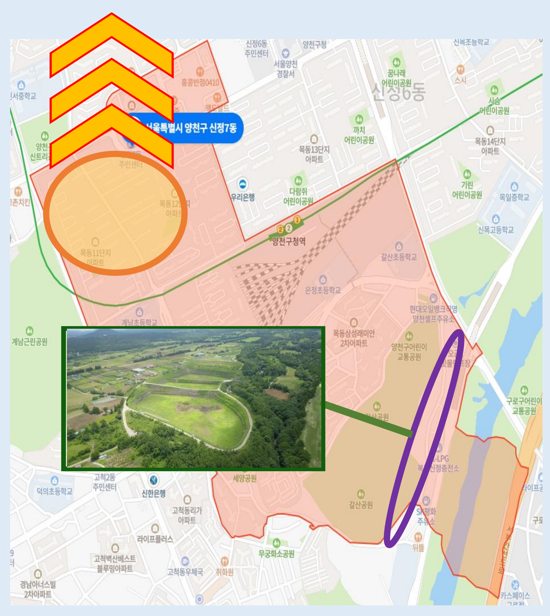
While our flood risk assessment analyzed hazard, vulnerability and capacity, it is hard to reduce the 'Vulnerability' aspect by urban planning measures unless a strong public policy is supported. Therefore, we have focused on reducing the hazard (average altitude, impervious surface rate, historical flooded area, historical flood damage) and increasing the capacity (green zone rate) which can be achieved by urban planning methods.

Aspect	Method	Related Section	Description
Facilities Management	Porous Pavement	Hazard	Using pervious facilities reduces impervious area and runoff. These measures will be helpful in reducing 'Hazard'.
	Tree-box Filter	Hazard	
Citizen Participation	Emergency Rocket	Capacity	These methods encourages and allows citizens to engage in responding to flood.
	Warning Street Light	Capacity	
Urban Planning	Building Plan	Hazard, Capacity	Using structural and non-structural mitigation techniques can significantly reduce the flood risk. Our methods mainly suggests LID (Low Impact Development).
	Zoning	Hazard, Capacity	

[Table 2] Resilience Plan for Sinjeong-7-dong. We have developed a resilience plan for Sinjeong-7-dong in 3 aspects, with each aspects containing 2 specific methods.

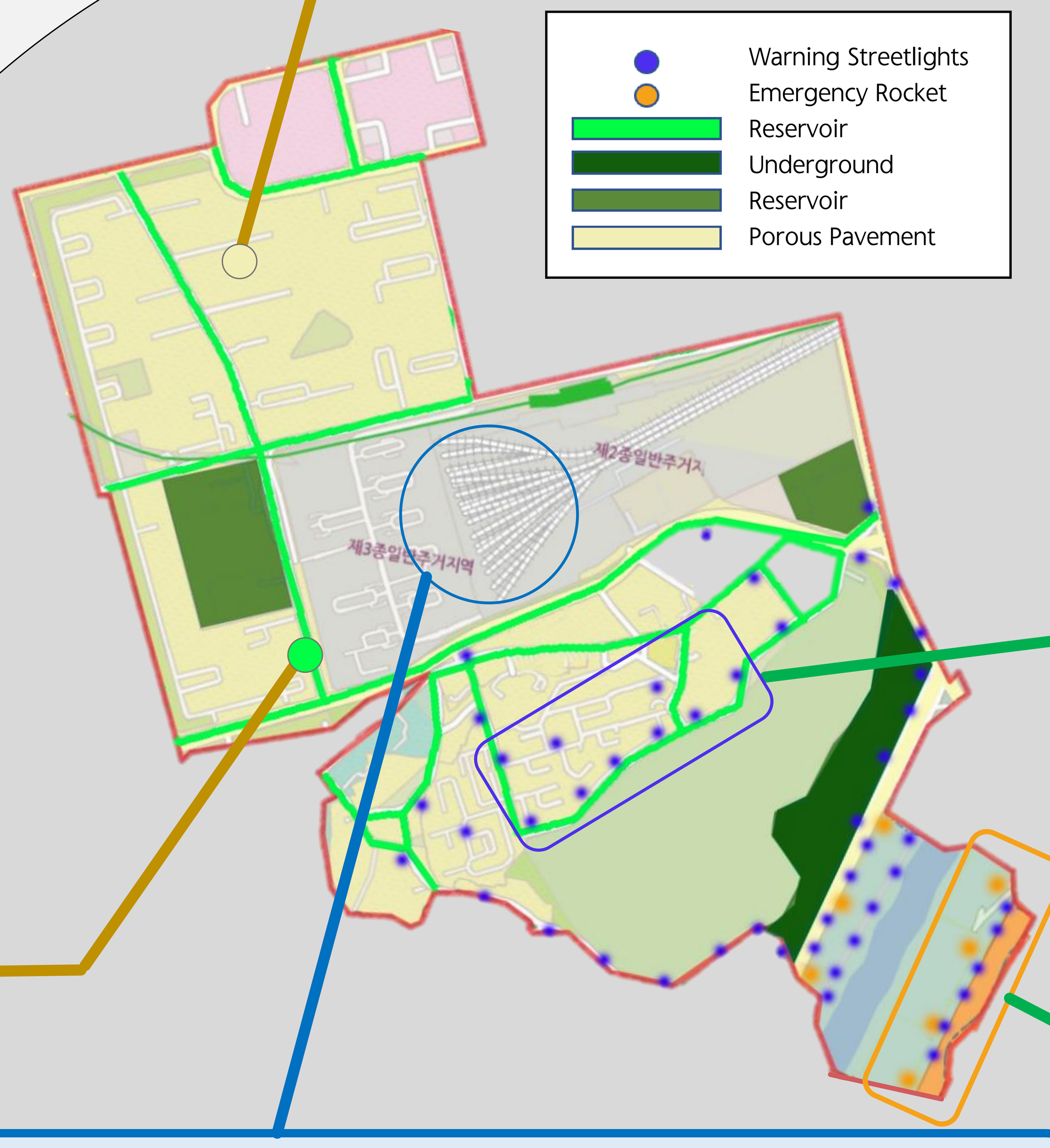
(1) Porous Pavement
Most of the roads in Sinjeong-7-dong are made with impervious materials like Asphalt, which prevents the rain from being absorbed into the ground. Therefore, porous pavement can be used in this area, especially in residential area (parking lots), to help rainwater permeate through the basement and reduce impervious surface rate of Sinjeong-7-dong.

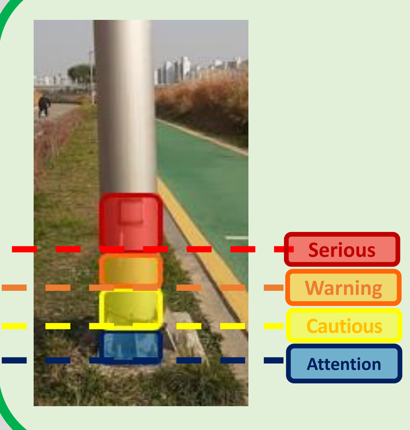
(6) Zoning
(Conjoint Renewal Program)



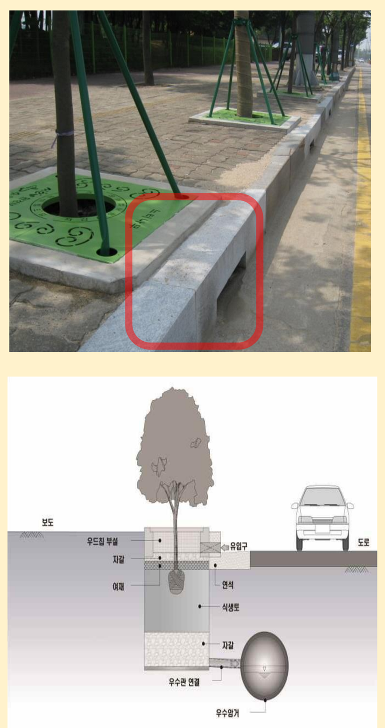
As described in above, the area that is circled with a purple oval is extremely vulnerable to flood due to its geographical features (U-type Low Land). In order to reduce its risk, the area should be changed from a man-living area into a reservoir park.

However, this requires the current residents in this area to move to other places. Therefore, the demand for this area must be moved to other safe areas, like the area that were not impacted in the 3D virtual simulation and are relatively safer than U-type low land. This can be achieved by giving incentives or subsidies to current residents to move to those districts.





(4) Warning Streetlight
Warning streetlights can help people to identify the risk level of the current situation on a real time basis. When the water rises to the level that are colored in yellow, orange, or red, people can easily notify it even from a distant place and report it to local authorities to request a district-wide warning. Also, we can set the system to trigger an early warning system automatically.



(2) Tree-box Filter
There are many trees along the road in Sinjeong-7-dong, and they can help in reducing the risk of flood, when used with tree-box filters.

Tree-box filters helps trees to absorb rainwater much more efficiently by inducing rainwater to run through the gap below the tree. The water can easily reach the roots of the tree or be absorbed in the ground through that gap.

Since most of the roads are impervious, if tree-box filters are installed in the trees that are next to the road, it can significantly reduce runoff and reduce flood risk.

(5) Building plan (Green Roof)

Green Roof Plan is one of the main techniques of LID (Low impact development). Considering the fact that Sinjeong-7-dong has many residential buildings with empty roof, green roof plan can be very effective. Making green rooftops will increase pervious surfaces in the district and therefore reduce flood risk of Sinjeong-7-dong.

(3) Emergency Rocket
Early response during flood period is critical. During flash flood, people can drift away in rivers. In these situations, emergency rockets can be helpful to save people's lives.

Emergency rockets can shoot emergency kits up to 60 meters in the aimed direction. Since they are easy to use, it encourages the participation of citizens. Also, the system automatically reports to local police and 911 center for assistance when the rocket is activated, which significantly reduces the response time.

05 Conclusion

Overall, we have achieved the 3 goals we have set in the beginning of this study – (1) assessing the flood risk of Seoul and identifying the most flood-vulnerable district in Seoul, (2) assessing the flood risk of the case study area, which was Sinjeong-7-dong, (3) developing a resilience plan for Sinjeong-7-dong. Although Sinjeong-7-dong already has a relative high capacity, its risk index showed a high value due to its high hazard, and people's vulnerability score. Moreover, we have effectively displayed the result of our flood risk assessment of Seoul by using GIS and coloring the districts with high risk-index score with darker color. A future study can be conducted on other districts with high risk-index score as well.

By using the features of Unity 3D, we were able to visualize the result of a 3D virtual flood simulation on Sinjeong-7-dong which helped us to identify which buildings are within the impact zone when a heavy rain with 30mm per hour intensity rains for more than 3, 6, or 12 hours. By visualizing the situation of a flood every hour, disaster management planners can develop a sequential response plan on an hourly basis. Moreover, we have conducted an on-site study to identify the flood risk of Sinjeong-7-dong in real word.

Based on our findings, we have developed a resilience plan for Sinjeong-7-dong in 3 aspects: Facilities Management, Citizen Participation, and Urban Planning. For facilities management, porous pavement and tree-box filter can help reduce hazard, especially in the impact zone that were identified in the virtual simulation. Second, emergency rocket and warning streetlights along the river can be an effective way to allow citizens to respond actively in flood situations. Lastly, using structural mitigation measures like green roof and non-structural mitigation measures like zoning will remove or reduce the fundamental risks that exists in Sinjeong-7-dong. Therefore, we suggest that these measures will be effective in reducing the risk and in increasing the response capacity of flood in Sinjeong-7-dong.

[Figure 14] Overview. We have identified the most flood-vulnerable district in Seoul and conducted a 3D virtual flood simulation and an on-site study. Based on these results, we have developed a resilience plan for Sinjeong-7-dong.

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