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# A Study on the Utilization of 3D Spatial-Grid for Coastal Area Management

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**ABSTRACT**

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Coastal areas adjacent to the sea are vulnerable to disasters every year due to repeated damage caused by typhoon-induced tsunamis, seawater flooding, and erosion. As such, a method for comprehensively managing coastal facilities and areas vulnerable to danger, based on underwater, aerial, and underground information included in the three-dimensional (3D) grid system was prepared, which can serve as an objective and scientific data source for the decision-making involved in effective coastal management. To this end, the concept and roles of the 3D spatial grid system are introduced in this study. In addition, through 3D data production and visualization utilizing this method and considering the characteristics of coastal areas, a method for comprehensive management of coastal areas through the 3D spatial grid system is proposed.

**ADDITIONAL INDEX WORDS:** *3D Spatial-Grid, coastal area management.*

## INTRODUCTION

South Korea suffers extensive damage each year due to typhoons and storms. Approximately 40% of such damage occurs in coastal areas. The damage to coastal areas nationwide due to natural disasters over the five years from 2008 to 2012 amounted to KRW 431.5 billion, representing approximately 67.1% of the total nationwide damage costs. Moreover, the damage is increasing due to coastal development, the increasing population, and the increasing number of facilities including fisheries and leisure activity infrastructure. In addition, considering that coastal areas are home to 27.1% of the national population (2012 data), natural disasters present a relatively larger threat to coastal areas than to the human population.

In South Korea, the national disaster management system (NDMS) is in operation to prevent national disasters, but it is difficult to perform preventive management because the system is focused on other efforts such as damage alert, overall damage calculation, restoration, and relief supply support. The coastal areas are subject to direct damage in the event of a typhoon or a tsunami, and damage to harbors, fishing ports, and fish farms occurs every year. For this reason, the government is currently managing coastal areas through various policies.

However, the existing management system provides spatial and attribute information separately due to its use of the two-dimensional (2D) thematic map listing GIS system. Therefore, there are limitations to the efficacy of management of the diverse information available about the coastal areas.

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As such, a comprehensive management of the diverse information concerning coastal areas, including monitoring, prediction, and response, through a system based on the three-dimensional (3D) spatial grid system is required. To this end, a complex management method based on the 3D spatial grid system which is capable of comprehensively expressing the various characteristics of the coastal areas was proposed.

### Overview of 3D Spatial Grid

The 3D spatial grid system conceptually refers to the system that uniformly divides the aerial, ground, underground, and underwater spatial ranges. Technically, it refers to the system that defines positional values in 3D space in grid form, as well as stores and manages such information (Figure 1).

In addition, the 3D spatial grid system consists of spatial grids and spatial tiles, and the coordinate system is based on Transverse Mercator (TM) of the GRS80 ellipsoid. The spatial grid system uses the octree technique and performs "$2^n$" division by increasing the resolution from top to bottom. As for grid ID allocation, IDs are assigned by consecutively increasing the numbers along the *x*-, *y*-, and *z*-axes with respect to the origin.

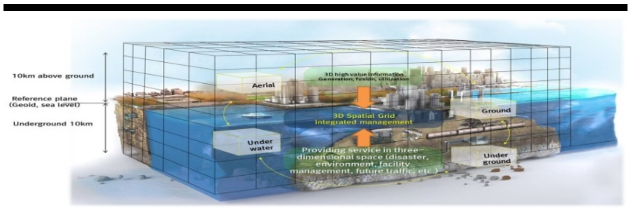


Figure 1. Conceptual diagram of the 3D spatial grid system.

Spatially, the system can be managed as a 3D spatial grid without space distinction, considering the characteristics of the coastal areas with aerial, ground, underground, and underwater continuity. Therefore, prediction and rapid response are possible using accurate positioning.

## METHODS

The 3D spatial grid system is a subject of consistent research and development so that the aerial, ground, underground, and underwater information can be comprehensively managed and various analyses can be conducted.

### Development of Main Functions

3D spatial grid systems consist of information, core, and service areas. The information area is composed of modules capable of converting, storing, and managing the data collected through linkage to the unique data format of the 3D spatial grid system. It integrates various data and stores the information of both the ambiguous virtual space and real-world space in the system. It stores various data in uniformly divided spaces so that aerial, ground, underground, and underwater information can be dealt with on a continuous basis. The core area analyzes the real world in cubic units, thereby enabling spatial analysis and visualization one step beyond the existing methods that analyze points, lines, and surfaces. The service area provides a module for developing applications based on the 3D spatial grid system. As seen, systems based on the 3D spatial grid system are a useful spatial information technology capable of integrating and managing information from various areas.

### Data Management

The 3D spatial grid system is a technology for the visualization of spatial information as well as for management, analysis, and visualization of this spatial information by dividing it into grids of a certain size in accordance with the determined method. In other words, the 2D grid data management technology was expanded to 3D in this system. There is also a difference between this system and other currently available 3D visualization services. In current 3D visualization methods, 3D objects are inputted on $x$ and $y$ coordinates based on 2D grids. In other words, all criteria are actually on 2D planes, but visualized as if they were in 3D. This existing method encounters difficulties in performing 3D analyses because it is more like a visualization model than a data management system, and the management of data itself is thus more difficult (Yoo *et al.*, 2018). Differences in the data management method between the 3D spatial grid system and the existing 3D modeling method are summarized in Table 1.

In addition, the existing 3D visualization system utilizes tiles as the management unit for the data. It manages the ground surface by dividing it into 2D grids of a certain size and displays the grids by storing and superimposing required object units in each grid. 3D spatial grid system divides the object and stores it inside the grid so that all information can be completely included in a single grid file without additional external information (Figure 2).

As such, 3D grid data were constructed based on digital maps of 2D buildings or facilities, including use of the digital elevation model(DEM), collected measurement data (*e.g.*, digital surface model(DSM) and obstacle information), and height. In addition, 3D Level of detail(LOD) was created by applying the octree structure and the run length compress(RLC) data compression algorithm so that data input, storage, and search functions could be available by space type (Figure 3).

Table 1. *Differences between the 3D spatial grid system and 3D modeling data management methods.*

| Category | 3D modeling method | 3D spatial grid system method |
|---|---|---|
| Basic operation | Data management in the form divided by 2D tiles regardless of the height | Management of all the 3D information of the management target by dividing it into grids |
| 2D Raster | Converted into 3D surfaces through DEM* and then visualized | Converted into 3D surfaces through DEM and then visualized on the grid where the data are located |
| 2D Vector | Modeled and then inserted into the reference point as a model | Managed as 3D grid data |
| 3D Raster | Made into images in tile units and visualized on the topographical surface created through DEM | Made into images in tile units and visualized on the topographical surface created through DEM |
| 3D Vector | Inserted into the designated input points in model units and tile units | Data are divided for management into grid units |
| Empty Space Management | Not supported | Empty space information is made into a grid and managed as another piece of information |
| Raster Visualization | Visualization after model creation by CPU | Raster data are transferred to GPU and visualized |
| Vector Visualization | Object-based visualization | Grid-based visualization |
| Data Search | Data search according to the altitude after 2D range search | 3D range search |

* Digital Elevation Model

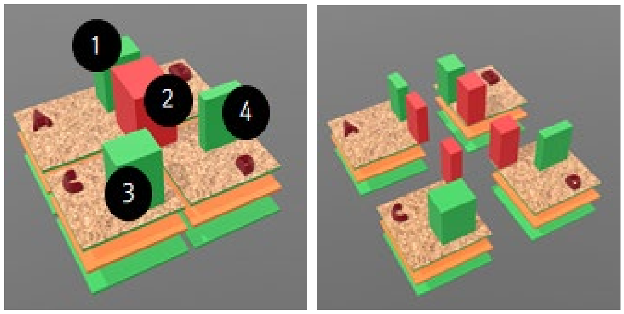


Figure 2. 3D spatial grid system data division and storage function: As shown in the left-hand figure, object 2 has information in all of the four tiles (A, B, C, and D) and settings can be made to prevent duplication during visualization, but data duplication occurs nonetheless. However, when the grids are loaded as shown in the right-hand figure, object duplication due to division does not occur because the object information is stored in grids A, B, C, and D, and all the information can be captured utilizing a single grid.

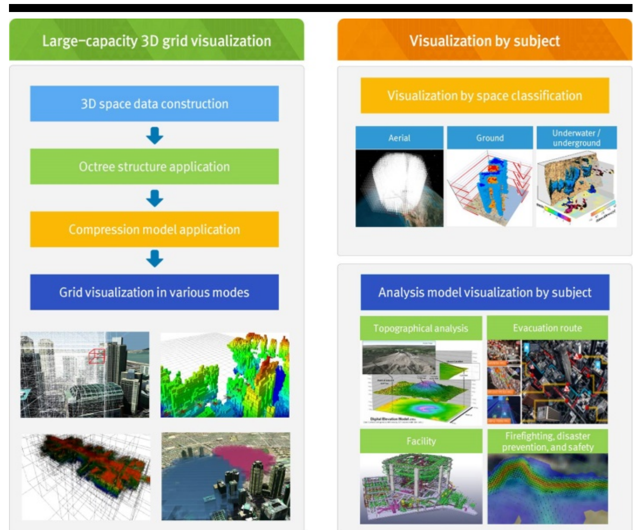


Figure 4. Visualization through the 3D spatial grid system.

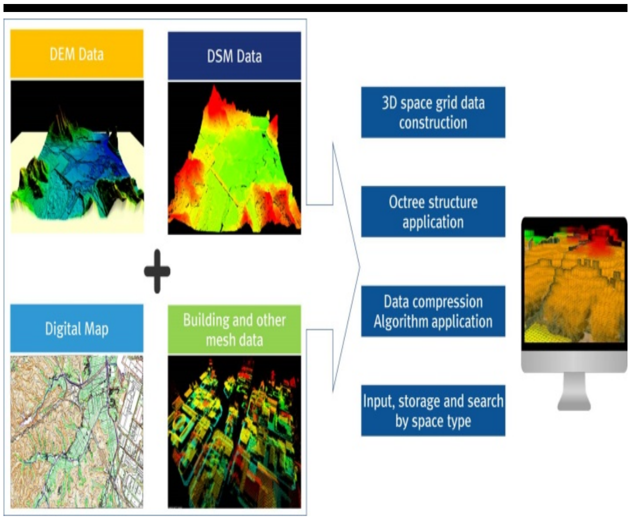


Figure 3. 3D spatial grid system implementation and data management technology.

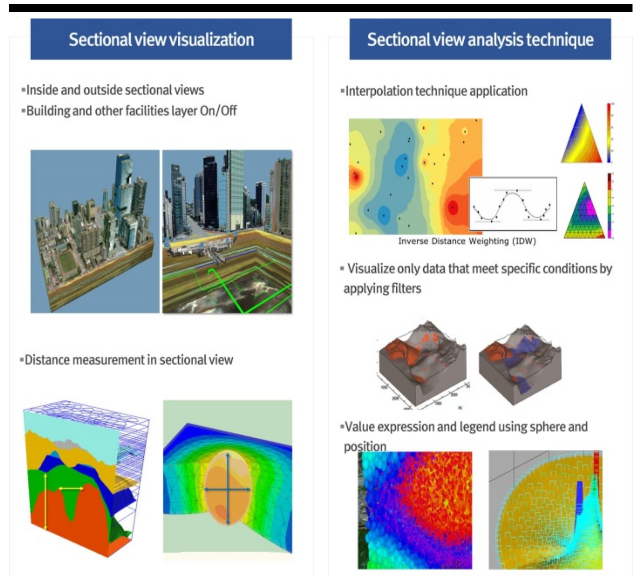


Figure 5. Analysis technique using the 3D spatial grid system.

### Visualization and Analysis through the 3D Spatial Grid System

3D visualization and the grid data visualization methods use a method of reading a model and then expressing it as a model at the appropriate position. As the grid data use the same method as Voxel in the 3D spatial grid system, the GPU can be sufficiently utilized. As the GPU enables the processing of far more calculations than in the existing method, further improvement can be expected in terms of speed and convenience (Figure 4).

In addition, 3D spatial object analysis was made possible in this system. In particular, the expression of comprehensive analysis results for facilities as well as aerial, ground, underground, and underwater spaces was possible through sectional view analysis (Figure 5).

## RESULTS

### Control and Monitoring

At regular time intervals, the areas where disasters had previously occurred were identified based on the 3D spatial grid system, and surroundings were comprehensively monitored.

For this, positional information ($x$, $y$, and $z$ coordinates), topographical information, weather information (*e.g.*, temperature, wind direction, and humidity), real-time information (sensor information concerning earthquakes and tsunamis), and CCTV information are included in the grid information system, and comprehensive monitoring is performed (Figure 6).

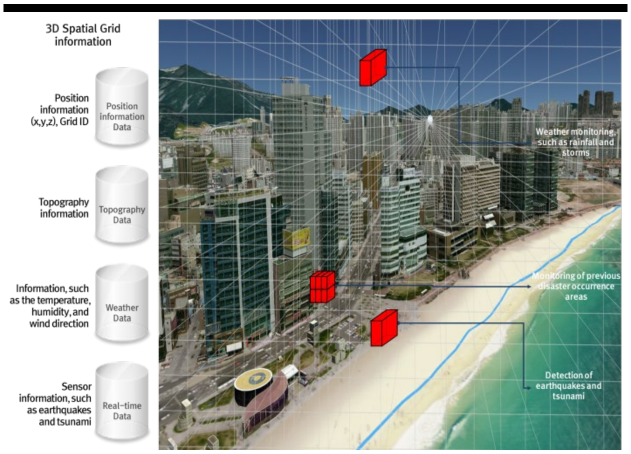

Figure 6. Control and monitoring based on the 3D spatial grid system.

**Prediction and Analysis**

In the event of a disaster, correlations between the corresponding grid, the surrounding grids, and the risk factors are comprehensively analyzed. The diffusion path as well as vulnerability and risk ranges are predicted and expressed in a 3D grid (Yang *et al.*, 2018).

The positional information (*x*, *y*, and *z* coordinates), topographical information, weather information (*e.g.*, temperature, wind direction, and humidity), facility information (buildings and dangerous facilities), real-time information (sensor information concerning earthquakes and tsunami), and other information (such as accident history information) were included (Figure 7).

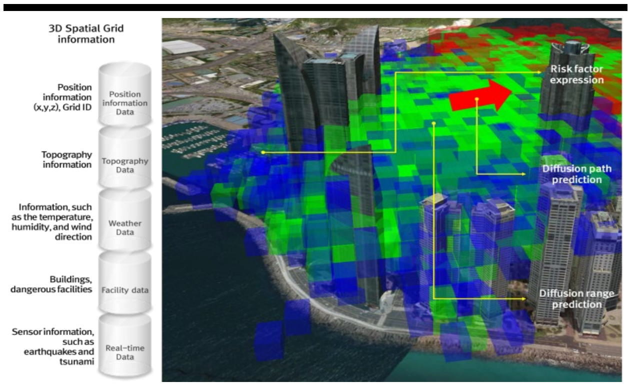

Figure 7. Prediction and analysis based on the 3D spatial grid system.

**Response and Support**

Based on the accurate position provided by the 3D spatial grid system, information such as appropriate response direction and evacuation route can be provided via analysis of information such as the diffusion path and range, as well as the complex situation by grid. In particular, grid information affected by the movement paths of pollution sources was displayed, and the influence of the corresponding grid was provided in a comprehensive manner (Figure 8).

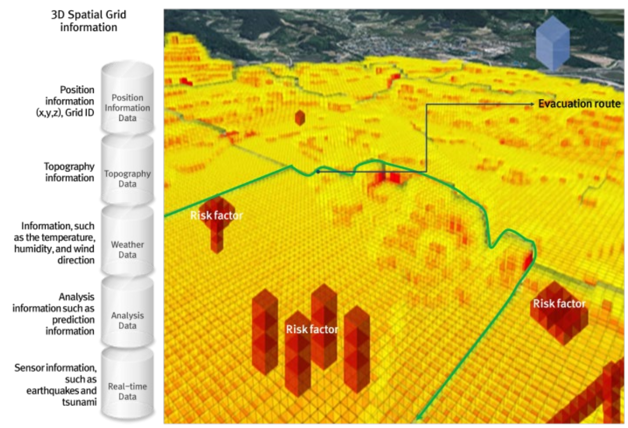

Figure 8. Response and support based on the 3D spatial grid system.

For this, positional information (*x*, *y*, and *z* coordinates), topographical information, weather information (*e.g.*, temperature, wind direction, and humidity), analyzed prediction information, and real-time information (sensor information concerning earthquakes and tsunami) must be included in the grid information, and a service module capable of relaying preparatory information to citizens is additionally required.

## DISCUSSION

There is a system for coastal area management in South Korea. However, the existing management system provides spatial and attribute information separately due to the construction of a 2D thematic map listing the GIS system that is focused on overall damage calculation for the effects of natural disasters.

The coastal areas of South Korea are vulnerable to disasters and considerable damage occurs every year due to typhoons and storms. Therefore, prediction and analysis to minimize damages as well as services for fast response in the event of a disaster are extremely important. To this end, the existing 3D spatial grid system was further developed to store diverse information (of aerial, ground, underground, and underwater nature) in 3D space or to conduct fast analysis, such as for prediction. However, it is an issue to comprehensively include massive aerial, ground, underground, and underwater information in a grid. As the monitoring, prediction, and response directions vary depending on data, it is necessary to first discuss which information must be selected and stored as basic data.

## CONCLUSIONS

In South Korea, the conventional system for coastal area management has limitations in its provision of accurate positional information because it uses 2D information to visualize the analyzed information in three dimensions.

The 3D spatial grid system rapidly stores diverse information (of aerial, ground, underground, and underwater nature) in 3D space and conducts analyses including predictive analysis, thus enabling easy information management (Ahn *et al.*, 2013). In addition, to effectively manage coastal areas with complex data, monitoring, prediction, and response directions were proposed based on a system that utilized the 3D spatial grid system.

Based on the results of this study, it is necessary to prevent disasters in coastal areas through the development of various analysis models, and to prepare more precise management systems in the future.

## ACKNOWLEDGEMENTS

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