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Original article

Establishing Required LOD and Positioning Accuracy for Indoor Spatial Information Applications in Public Administrative Works

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Abstract

Due to the large size and high complexity of modern buildings, the interest and the studies about indoor spatial information are increasing. Previous studies related to indoor spatial information were mostly about relevant technologies, and the application of indoor spatial information has been less studied.

In the present study, the public administrative work areas where indoor spatial information may be applied were identified by using a modified delphi technique. And the indoor LOD (Level of Detail) and indoor positioning accuracy for indoor spatial information applications considering user requirements was established as standards for efficiently establishing and providing services. The required LOD and positioning accuracy for services was established by reestablishing indoor LOD and positioning accuracy and classifying services with reference to those. The indoor LOD was reestablished from LOD 0 to 4 by focusing on service utilization and general recognition, and the positioning accuracy was reestablished in three levels by considering the accuracy of the present positioning technology and service utilization status.

Keywords : Level of Detail, Indoor GIS, Indoor LBS, Use-Case

1. Introduction

With the development of construction technologies in the modern society, huge and high-rise buildings are being constructed and the complexity of buildings is also increasing. Hence, indoor space is drawing more interest, and the utilization of indoor spatial information is attracting domestic and international attention (Kim *et al*., 2016). Current international standards about indoor space include CityGML (OGC, 2012) and IndoorGML (OGC, 2014) developed by OGC (Open Geospatial Consortium). Various applications are expected to be made in the future on the basis of IndoorGML, the international standards for topological data models of indoor space (Li and Lee, 2013).

In the domestic fields relevant to indoor spatial information, three-dimensional indoor models have been established for public facilities and services are provided under the direction of governmental authorities, such as the Ministry of Land, Infrastructure and Transport and Seoul Metropolitan City. However, since previous studies have been focused on the establishment of indoor space data, practical applications have been rarely found. The number of domestic indoor LBS (Location-based Services) currently provided is 27, and only 30% of the services are for the public sector (Seoul, 2015). Therefore, there is a need for identifying actually applicable services.

Identification of various services requires an understanding of the current status of indoor spatial information utilization and the technological levels as well as the investigation of user requirements. For example, an indoor space model should be efficiently established because it requires considerable cost and time depending on the LOD (Level

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of Detail). Identification of services that may be actually put into practice requires clear understanding of the need and applicability as well as the requirements in the establishment and management. In the present study, the indoor spatial information service users and the public administrative works to which the services may be applied were identified in the public sector where the spatial information service applications are relatively few at present, the user requirements and the service applicability were analyzed to identify the indoor spatial information application areas in the public administrative works for practical application. In addition, to efficiently establish and provide the identified services, required LOD and positioning accuracy for indoor spatial information applications was established by classifying the services with reference to indoor LOD and positioning accuracy.

This article consists of Chapter 2 Relevant Studies, Chapter 3 Identification of Indoor Spatial Information Applications, Chapter 4 Establishing Required LOD and Positioning Accuracy for Indoor Spatial Information Applications, and Chapter 5 Conclusions. Chapter 2 discusses the previous studies about the indoor spatial information-related technologies and their method of identifying applications, Chapter 3 conducts the method of identifying indoor spatial information applications, Chapter 4 describes the establishing required LOD and positioning accuracy for indoor spatial information applications, and Chapter 5 provides the conclusions of the present study.

2. Previous Studies

Chapter 2 discusses the current status and application examples of the technologies and studies for providing indoor LBS. In addition, previous studies on the method of identifying indoor space information service applications are reviewed in this Chapter.

Regarding indoor spatial information, there are studies on indoor space modeling, indoor positioning, and visualization. With regard to indoor positioning technology, which is a location determination technology, Wi-Fi, geomagnetism sensors, and RFID are most frequently utilized at present. The positioning principle of the representative Wi-Fi-based positioning technology is a fingerprinting technology to measure signal intensity at several known reference positions to prepare a radio map in advance, and then to compare the strength of the signal received by a terminal with the radio map to determine the position (Lee and Kim, 2015). The accuracy of the Wi-Fi-based positioning technology is generally from 1 to 10 m, and may be decreased by interference depending on the environment. When combined with a dead reckoning technology using an inertial navigation system, such as an acceleration sensor and a gyro-sensor, the accuracy may be increased to 1 to 5 m. The positioning technology using a geomagnetism sensor is based on geomagnetism that is distorted by a building to have a unique value as well as a fingerprinting technology. The accuracy is about 1 to 2 m (Mautz, 2012). The geomagnetism sensor-based technology is utilized with the Wi-Fi-based technology and an inertial navigation system. As positioning accuracy improved by technology development, more detailed and various services on indoor navigation and control will be available.

Indoor space modeling technologies, which are for establishing spatial shape data, include terrestrial laser scanning, as-built drawing, BIM (Building Information Modeling), omni-directional images, and mobile mapping system (Oh and Lee, 2012; Seoul, 2015). The indoor space modeling method using as-built drawings (CAD drawings) has a lower acurracy, but it is useful for simple guide services as economical on establishment cost and enables intuitive understanding of building shape with two-dimensional data. The terrestrial LiDAR scanning technology enables the acquisition of very precise data using high-precision LiDAR sensors and may be applied to the interconnection of the indoor and outdoor space information. BIM, having various and detailed information of a building, may be useful for services of indoor spatial information requiring detailed visualization and rich property information. However, since BIM includes very detailed information, even the information about the construction materials, the amount of data should be reduced in accordance of the requirements for each service. The indoor space modeling based on omni-directional images, which is the very detail method of expressing the real world, is useful for services where the real environment should be provided without modification, such as Google Art Project, and Naver and Daum Store View services.

In indoor space visualization, various studies have been conducted on indoor LOD (Kang and Lee, 2014; Benjamin *et al*., 2009). Benjamin *et al*. (2009) classified indoor LOD according to the purpose of applications and suggested an indoor space LOD model focused on geometric expression of objects in an indoor space for the purpose of path search in buildings. The suggested model consists of four LODs from LOD 1 to LOD 4, and provides spatial profiles of different thematic, geometric, topological, and visual complexities. In the suggested model, LOD 1 and 2 are two-dimensional, and LOD 3 and 4 are three-dimensional. The geometric accuracy of LOD 1 and 2 is 0.5 m and 0.2 m (position), respectively, and that of LOD 3 and 4 is 0.2/0.2 m and 0.05/0.05 m (position/height), respectively. Kang and Lee (2014) suggested an LOD model depending on the indoor space expression method. The suggested LOD model is an LOD model for application service, wherein the LOD is not defined by a geometric expression depending on the scale but by the data type or method of indoor space data expression. The types of data used for indoor space modeling were largely classified as image and geometric data, and the indoor space LOD was divided into four levels with the expression method, accuracy, and applicable services defined for each LOD.

Some of the relevant studies have suggested applications that are possible both theoretically and technically. However, the studies were limited to developer-centered studies where the practical usability of the suggested technologies and applications, the works requiring the applications, and the level of service needed were neither specifically mentioned nor sufficiently discussed. A service should be appropriately provided according to the user demand and the purpose, and various applications should be made depending on the technological development. Therefore, studies need to be conducted to enable various applications by identifying applicable services reflecting user requirements.

As an example of studies for identifying indoor space information applications, Sim (2012) identified specific elements. Sim (2012) employed the Delphi technique for identifying prior application items by performing a three-round survey with an expert group and identifying major BIM application items through a statistical verification of the survey results, and also employed the AHP (Analytic Hierarchy Process) method to find out the importance and priority of the BIM application items. As a similar study conducted to develop an improvement method by collect expert opinions through a survey, Choi (2013) performed a survey with relevant work employees, experts, and service users to develop an improvement method on the basis of the opinions collected from the actual work experts.

In addition, Jang *et al*. (2010) suggested a service identification framework for SOA (Service Oriented Architecture) realization including a process of identifying requirements through a stakeholder need analysis, providing specific procedures to enhance the service re-usability and flexibility and to defining and identify services. The suggested framework was expected to play an important role in the improvement of SOA development methodology.

As discussed in this Chapter, the current indoor spatial information-related technologies are limited in the application, and thus more studies are needed to identify actually applicable services. In the present study, a method of identifying indoor spatial information applications using a survey method that is frequently used for the application identification was suggested, and application services were identified by using the suggested method. In addition, the present study establishes the required LOD and positioning accuracy for indoor spatial information applications considering user requirements to provide the identified services, enhancing the overall appreciation of service applications.

3. Identification of Indoor Spatial Information Applications

This study conducted a survey method using a modified Delphi technique as a methodology for identifying applicable and usable services in each service identification scope (Fig. 1).

The modified Delphi technique conduct a condensed survey by utilizing a structured questionnaire from the first round of survey, can increase the survey efficiency despite the smaller number of survey rounds (Custer *et al*., 1999). This study efficiently derive various expert opinions through

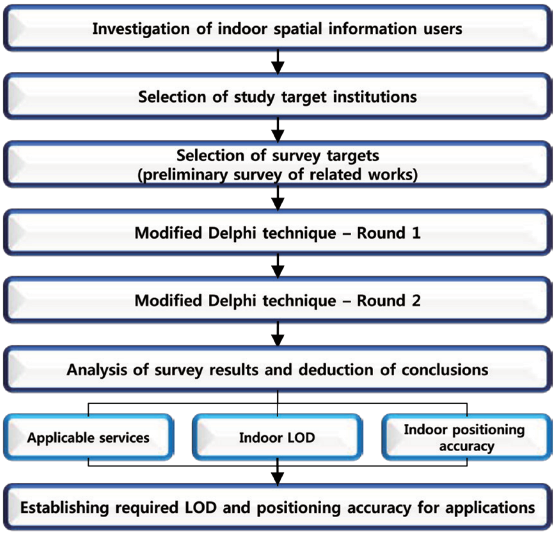


Fig. 1. Process for identifying applications

two rounds of surveying consisting of one basic questionnaire survey and one in-depth survey by face-to-face interview.

As described above, The applications in the public sector are few. Therefore, this study was conducted with public administrative works by focusing on the demand in the public sector. A target institution was Seoul Metropolitan City which have many affiliated public institutions. Their public administrative works are various, so all the works were surveyed to find out various applications from potential work area.

Services that may be practically applicable may be identified by investigating the need in actual works, possibility of application, and requirements in the establishment and management. Hence, all the workers who are in charge of the works related to indoor space were investigated, and the survey subjects were selected among them by considering the appropriateness for the survey.

The first round basic survey was performed by using a structured questionnaire which was sent through e-mail to 552 relevant workers, and 86 of the workers responded. The basic survey questionnaire was prepared through an interview with a Seoul Metropolitan City public officer in charge of spatial information and literature survey of relevant studies to include 23 questions in four areas, which were general status of survey subjects, understanding of indoor space-related works, discovery of indoor spatial information applications, and other opinions freely described.

The second round in-depth survey was performed in a face-to-face interview format to collect more detailed opinions from 28 work practitioners highly related to each of the work areas. The in-depth survey questions were designed to investigate the accurate works of the subjects, current application of indoor spatial information to their works, and potential applications, and to derive detailed requirements and suggestions. In addition, during the interview, explanation was provided about the currently provided types of services, such as indoor facility simulation, navigation service, and CCTV-related services, with an illustrative example of three-dimensional indoor spatial information modeling accomplishment to help the subjects have a better understanding and to investigate the need of data for the indoor spatial information establishment as well as the requirements for the application to their works.

The result of the first round survey identified internal administrative workers and society and traffic disadvantaged people as the prioritized service targets, firstly in the service aspect. The prioritized service areas requiring the indoor spatial information service were found to be fire-fighting, disaster, and accident-related facilities and equipment management, geographic information, and tourism in order. The identified work areas to which indoor spatial information is applicable were facility management (17%), guidance (49%), space management (22%), security control (11%), etc. in terms of wide range. The subjects' requirement identified was public relations about indoor spatial information. With regard to data establishment, the identified high-degree requirements included diversification of applicable data, establishment and provision of data in accordance with application goals, and securing of data accuracy. Other requirements included data downsizing and easy-to-use system establishment. With regard to data management, the top priority requirement was continuous data update, followed by the arrangement of and the education for professional human resources related to indoor spatial information and the simplification of administrative works relevant to indoor spatial information.

The second round survey showed that the services should be connected with the systems that are currently used for actual works and that service utilization environments should be prepared in consideration of the uniqueness of each work area. In the aspect of data establishment, the highest degree of requirements included data establishment and provision procedures considering the applicability in each work area, not one-sided establishment and provision, and the establishment after investigating the data need LOD for each service applicable to works. The aspect of data management required a well-defined management system with clear data management subjects. Also required were prevention of additional work load due to the indoor spatial information and preparation of security issue-related countermeasures for the service provision to citizens.

In the present study, a total of 29 services in five categories were identified as services applicable to indoor space-related works on the basis of the two rounds of surveying, wherein the five categories were indoor facility management, indoor monitoring, indoor guidance, indoor simulation, and indoor work assistance (Table 1). The identified services are services that may be applied to the actual works of practitioners in each field and they were identified by the second in-depth survey performed on the basis of the result of the first round basic survey. The fire-fighting training indoor simulation, civil defense shelter facility guidance, museum virtual exhibition, indoor guidance service for the disabled have been partially applied. Services, such as material management system, national and public daycare centers on-site survey, in-station advertisement facility management, required connection of the indoor spatial information with the conventional systems. The category of indoor guidance, where the greatest number of services was identified, included general convenience services for citizens required in many kinds of works. Beside the indoor guidance, 65% of the identified services were services required by actual practitioners of internal administrative works, such as fire-fighting training or security control, that were closely related to the actual works.

The identified applicable services had different

Table 1. Indoor spatial information applications for actual works

Item	Indoor spatial information applications for actual works	
a. Indoor guidance (for citizens)	a-1	Shopping area
	a-2	Concert hall indoor facilities
	a-3	Civil defense shelter facilities
	a-4	Public buildings
	a-5	Construction workers, dangerous areas, and no-go area alerts
	a-6	Tourist attraction
	a-7	Social welfare centers
	a-8	National and public daycare centers
	a-9	Walking paths for the disabled
	a-10	Gates and exits
b. Indoor facility management	b-1	Indoor convenience facilities management
	b-2	Fire-fighting/safety facility management
	b-3	In-station advertisement facilities management
	b-4	In-station arts display management
	b-5	Fire-fighting/disaster prevention vulnerable areas management
c. Indoor simulation	c-1	Concert hall lightings
	c-2	Indoor general facilities arrangement
	c-3	Communication lines and relevant facilities arrangement
	c-4	Exhibited objects arrangement
	c-5	Fire-fighting training
d. Indoor monitoring	d-1	CCTV (Security control, CCTV control and intuitive visualization)
	d-2	Positioning of control center in construction worker emergency
	d-3	Rescue in safety accidents through the investigation of the number and location of people
e. Indoor work assistance	e-1	Mapping of public sphere
	e-2	Assistance to in-station shop contracts and management
	e-3	Anti-terrorism goals analysis system
	e-4	Material management system
	e-5	On-site investigation of national and public daycare centers
	e-6	Exhibition planning based on visitor statistics for each museum space

requirements for data type, accuracy, and data and system management in each field and service. Efficiency, which is most important in the actual establishment and application of the identified services, is closely related to data type, resolution, and accuracy among the service requirements. Therefore, on the basis of the subjects' data requirements identified by the two rounds of surveying, the data LOD and positioning accuracy needed for each service were identified, and the required LOD and positioning accuracy for indoor spatial information applications was established by reflecting the results.

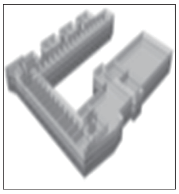
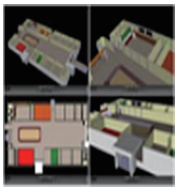
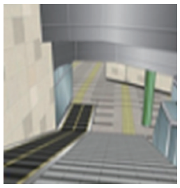
4. Establishing Required LOD and Positioning Accuracy for Indoor Spatial Information Applications

The data LOD and service accuracy for indoor LBS should be efficiently provided because they are closely related to the cost, convenience, and intuitiveness. Hence, the requirements of the service users should be clearly investigated to establish and provide data in accordance with the application purposes. In the present study, to establish and provide data in accordance with the application purposes, classification criteria for indoor LOD and positioning accuracy were firstly defined, and types of applicable services were established on the basis of the users' data requirements for each service.

4.1 Indoor LOD

First, the direction of data establishment was provided by applying the indoor LOD of applicable services. The indoor LOD classification criteria were re-established as five-stage LOD concept by partially modifying the indoor LOD model provided by Kang and Lee (2014) (Table 2). The re-establishment was focused on service application and based on opinion of practitioners (survey target) about required indoor spatial data for utilizing indoor spatial information. Especially simple 3D bounding box was demanded for services unlike existing study. The degree of simplicity and detailedness of the five-stage LOD representing the degree of spatial expression were re-established in an LOD model including 2D, 2.5D, and 3D LODs. LOD 0 corresponds to 2D CAD data, and LOD 1 corresponds to 3D omni-directional image data of 2.5D. LOD 2 corresponds to simple box-type 3D data expressing simple geometry, LOD 3 corresponds to 3D data combining simple geometry and texture file, LOD 4 corresponds to 3D data combining detailed geometry and detailed texture file, wherein LOD 4 corresponds to the LOD 4 of CityGML.

Table 2. Characteristics of indoor LOD model (Kang and Lee, 2014)

Characteristics	Image		Geometric Modeling		
	LOD 0	LOD 1	LOD 2	LOD 3	LOD4
Model scale description	 2D floor plans	 3D panoramic images	 3D rooms (bounding box)	 Detailed 3D rooms	 High detailed 3D rooms
Geometric accuracy (position[/height])	Very low (1.5m/1.5m)	Low (1m/1m)	Middle (0.8m/0.8m)	High (0.4m/0.4m)	Very high (0.2m/0.2m)
Generalization	Structural features: > 1.5m X 1.5m	-	Structural features: > 1.2m X 1.2m	Object as real features; > 0.5m X 0.5m /1m	Constructive elements
Data for Visualization	2D CAD drawing, floor plan images	Omni-directional images	Very simple geometry	Simple geometry + texture	Geometry modeling + detailed texture

4.2 Indoor positioning accuracy

Second, the direction of the services was provided by classifying the positioning accuracy of the applicable services. As shown in Table 3, the current accuracy of indoor positioning may be briefly classified into three levels of low, mid, and high levels with reference to the applicability and technological levels (Resolution of 10m or higher is meaningless. Classification of layer information is assumed.). The levels of positioning accuracy were re-established to apply to each of the identified indoor spatial information services (Table 4).

The positioning accuracy was classified into three levels, including w/o (without), low-mid, and mid-high levels. The accuracy range of each of the positioning accuracy levels was determined as actually available accuracy range for actual service application by considering the accuracy of the current positioning technologies. The maximum value of range is 10 m, because the accuracy over 10 m is too high for indoor services. And the minimum value of range is 5 m, based on qualified accuracy of the WiFi-based indoor positioning (ETRI, 2010). For practical establishment of services, we only considered the WiFi-based indoor positioning. Except WiFi access point which is substantially installed already, other indoor positioning type require additional cost. Classification of accuracy range into three levels was based on opinion of practitioners about required positioning accuracy for each service (e.g. services do not need indoor positioning), and considered service criteria.

The service application criteria for each level were classified with reference to the recognition subjects and the service utilization situations. The low-mid accuracy level was for services for spatial recognition or general situations, while the mid-high accuracy level was for subject recognition or emergent situations.

Table 3. Recent indoor positioning accuracy

Accuracy Classification	Low	Mid	High
Positioning Accuracy	10m	5m	2m
Type	WiFi	WiFi + additional data	WiFi + Magnetic Field

Table 4. Reclassification of indoor positioning accuracy

Accuracy Classification	w/o	Low-Mid	Mid-High
Positioning Accuracy	-	10-5m	5-2m
Service Criteria	-	Space recognition/ general situation	Object recognition/ emergency situation

4.3 Establishing required LOD and positioning accuracy for indoor spatial information applications

Table 5 shows the results obtained by applying the LOD re-established on the basis of the opinions of the practitioners of individual services identified by the modified Delphi technique. Required model scale and geometry accuracy by practitioners of individual services was criteria to apply. Also, the positioning accuracy levels re-classified for each of the identified services were applied by referring to the user requirements in terms of accuracy for indoor applications provided by a previous study (Mautz, 2012) as well as the opinions of actual practitioners of the works (Table 5).

Table 5. Classification of applicable service LOD & positioning accuracy

Item	Applicable service	Indoor Space Representations (LODs)					Indoor Positioning Accuracy		
		0	1	2	3	4	w/o	L-M	M-H
a. Indoor guidance (for citizens)	a-1	O	O	O	O			O	
	a-2		O		O	O		O	
	a-3	O	O	O	O				O
	a-4	O	O	O	O			O	
	a-5	O							O
	a-6	O					O		
	a-7	O	O	O	O			O	
	a-8		O				O		

	a-9	O							O
	a-10	O		O	O				O
b. Indoor facility management	b-1	O			O			O	
	b-2	O			O				O
	b-3		O			O			O
	b-4		O					O	
	b-5		O			O		O	
c. Indoor simulation	c-1					O	O		
	c-2	O			O		O		
	c-3				O	O	O		
	c-4		O		O		O		
	c-5				O		O		
d. Indoor monitoring	d-1			O	O		O		
	d-2	O		O					O
	d-3	O		O					O
e. Indoor work assistance	e-1		O		O		O		
	e-2	O						O	
	e-3	O		O	O				O
	e-4				O	O		O	
	e-5	O	O				O		
	e-6	O		O			O		

Fig. 2 shows the mapping of the services with reference to the indoor LOD and the indoor positioning accuracy, the two factors applied to the actual establishment and provision of the identified applicable services. First, the minimum requirement satisfaction LOD was mapped among the applicable LODs of each service in order to investigate the lowest LOD requirement for each of the identified services (Fig. 2(a)). The mapping result showed that 16 out of the 29 identified services required a low LOD and a low level of positioning accuracy. Second, the minimum requirement satisfaction LOD was mapped between LOD 2 and 4, the 3D level LODs applicable to each of the services in order to investigate the lowest LOD requirement of the services (Fig. 2(b)). The mapping result showed that 10 out of the 29 identified services could be provided at LOD 2.

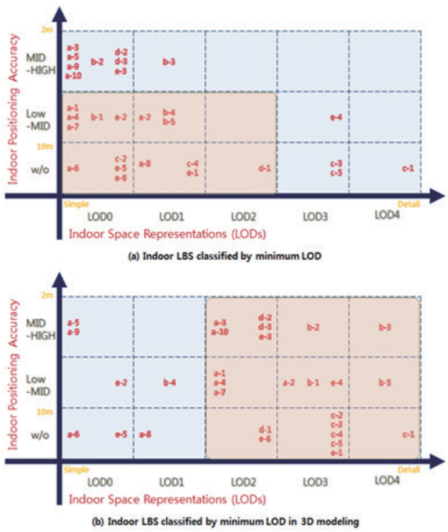


Fig. 2. Establishing required LOD and positioning accuracy for indoor spatial information applications

With regard to the works to which the services identified in Fig. 2(a) may be applied, all the services included in the categories of indoor guidance (a) and indoor facility management (b) may be sufficiently provided at LOD 0 to 1, but simulation services, such as concert hall lightings (c-1), communication lines and relevant facilities arrangement (c-3), and fire-fighting training (c-5), the indoor work assistance services, such as material management system (e-4), the indoor monitoring service using CCTV (d-1) require at least LOD 2. With regard to the positioning accuracy requirements of the services, about 70% of the services require a low level of positioning accuracy, and even 38% of the services, including indoor guidance services for tourist attractions and daycare center, mapping of public sphere, indoor monitoring using CCTV, and all the services included in the indoor simulation category (c) do not require indoor positioning.

3D visualization of services (Fig. 2(b)) is possible in 22 services, but seven services do not require 3D visualization for the reasons of intuitiveness or others. All indoor guidance services (a), except the concert hall indoor facilities guidance service (a-2), may be provided at LOD 2. The d-2 and e-6 services that do not require complicated visualization require only LOD 2. The b-3, b-5, and c-1 services require the highest LOD because the services require management or visualization of small-sized objects.

The mapping result showed that many of the services are needed for or applicable to current works even at a low LOD and a low level of positioning accuracy. Many services may be applied to the works of the public sector even though the data LOD or the level of positioning accuracy may not be high.

In the present Section, the classification criteria for indoor LOD and indoor positioning accuracy were re-established by focusing on service applications, and the types of applicable services identified by considering the two re-established factors were established. The required LOD and positioning accuracy for indoor spatial information applications established in the present study may be a guideline for future establishment and provision of indoor spatial information services for each work field.

5. Conclusions

Previous studies related to indoor spatial information were mostly about relevant technologies, and the application of indoor spatial information has been less studied. In the present study, the public administrative work areas where indoor spatial information may be applied were identified by using a modified delphi technique, and the required LOD and positioning accuracy for indoor spatial information applications was established

The present study was conducted with Seoul Metropolitan City to identify the service users and the public administrative works to which the services may be applied. Two rounds of surveying were performed by using a modified Delphi technique to analyze the practitioners' requirements with regard to the indoor spatial information service application and the applicability of the services. Based on the result, the works to which the indoor spatial information services may be applied as well as the applicable services were identified. The identified services were classified with reference to the indoor LOD and positioning accuracy re-established for efficient establishment and the required LOD and positioning accuracy for indoor spatial information applications was established.

The results showed that many services can be applied without a high LOD or a high level of positioning accuracy. Therefore, to provide effective services, data and technologies appropriate for each service type should be utilized, rather than simply focusing on the precision. The services should be established efficiently by considering that point, and the services may be gradually improved as the cost for establishing data and services is decreased with the development of technologies.

The limitations of the present study are the absence of appropriateness verification through actual service application following the data establishment according to the service type classification and the absence of LOD establishment for the features of each service. Further studies may need to be conducted to verify the appropriateness of the establishment and to define LOD for each feature of the services by reflecting the considerations for each service.

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