Reference Investigation Concerning Utilization
of 3D Information in Construction Industry

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Abstract: Recently, CALS/EC is rapidly being promoted with the development of information technology. CALS/EC aims at an increase in efficiency of business by carrying out information exchange, cooperation, sharing, and reuse for digital results in the process of the life cycle of investigation, planning, design, construction, and maintenance management in public works. In CALS/EC, attention is being focused on utilization of 3D information for CAD or GIS. In order to promote CALS/EC in the future, it is very important to utilize 3D information. The purpose of this present research is to undertake reference investigation about practical utilization of 3D information in the construction industry. Moreover, the present condition of practical utilization of 3D information in the construction industry was analyzed.

Keywords: 3D Information, Construction Industry, CALS/EC, Reference Investigation

1. はじめに

In recent years in the construction industry, Construction CALS/EC is being aggressively promoted¹-³. Construction CALS/EC is an organization with a goal to improve business efficiency by computerizing documents of investigation, planning, design, construction, and maintenance management – which complement to life-cycle process – of public works and projects, and by promoting information exchange, collaboration, sharing, and reuse⁴-⁶. Recently, among electronic information that is being used in the construction industry, application of 3D information is gaining attention⁷-⁸. In the construction industry, there are many occasions when 3D information is handled by using systems such as CAD and GIS⁹. For the promotion of the next generation of the CALS/EC, effective utilization of 3D information is extremely important.

In order to use 3D information in the construction industry, it is necessary to grasp the current situation. By recognizing at which construction field and business phase the 3D information is currently being used, strategy for effectively using 3D information can be planned.

Therefore, in this research, investigation on documents related to the use of 3D information of the construction industry was performed. In documents such as academic thesis papers and technology reports, the latest and advanced cases are reported, and investigating on those cases is extremely useful. The documents are collected, and by collectively analyzing each of the documents, effective use of 3D information in the construction industry will be studied.

2. 3D情報の活用

In this research, documents related to application of 3D information of the construction industry are investigated. From each of the documents, keyword is extracted. Also, by using the extracted keyword, the documents are classified into category of construction field and business phase.

To the classified documents, “analysis of the number of documents in terms of construction field / business phase” and “analysis of keyword frequency in terms of construction field / business phase” will be performed. From the analysis, on what kind of

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construction field and business phase that the 3D information is being used will be grasped. In addition, by performing frequency analysis on the extracted keywords, we will be able to determine what kind of technology is gaining attention in each construction field and each business phase.

By the above investigation, situation of application of 3D information in the construction industry will be studied.

### Table 1  Combinations of Keywords that were Used in Document Search and their Document Count

<table>
<thead>
<tr>
<th>Keywords</th>
<th>Document Count</th>
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<td></td>
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</table>

### 3. ผลการวิจัยตามลำดับการจัดเรียงตามค่าในการค้นหารายการ

In this research, as a prior step of document investigation, 2 processes of “gathering and sorting of documents” and “optimization of keyword extraction” were performed. Each result is summarized below.

(1) ขั้นตอนการจัดเรียงตามค่าในการค้นหารายการ

As a first task of document investigation, documents related to the application of 3D information were collected. Database used in document collection

![Fig.1 Example of Extracted and Optimized Keywords](image_url)
is JOIS (JST Online Information System) that is offered by Japan Science and Technology Agency (JST). The gathering of the documents was done by document search by keywords. In the search, combination of 11 keywords was used. In this research, in order to perform investigation on application of 3D information, keyword “3D” was adopted to all of the combinations. In addition, keywords of “CAD” and “GIS”, which have deep relations with computerization of construction industry, were used. Search result for each of the 11 combinations that used other keywords is as shown in Table 1. Document search with AND search was performed by using the keyword. As a result of the search, 282 documents were gathered and sorted.

2) 요해분석 및 문헌조회의 도구

In order to classify the collected documents into construction field or business phase, extraction of optimum keywords for every documents was performed. This task will be performed in the following 5 processes; a) extraction of keywords from document abstract, b) optimization of the extracted keywords, c) production of index using pre-established keywords, d) combination of extracted keywords and the indexes, e) optimization of keywords and indexes. Details of each process will be explained below. Example of keyword extraction and optimization is as shown in Fig.1.

1) 키워드 추출 및 최적화 프로세스

In keyword extraction, after breaking down each of the document’s abstract in terms of words using morphological analysis, they were extracted manually. Important keywords in each of the document were extracted.

2) 키워드 최적화 및 최적화 프로세스

Optimization of the extracted keyword was performed. Because the number of the extracted keywords will be enormous, executing process optimization will be required. For process optimization, keyword regularization, keyword decomposition, and deletion of unnecessary keyword are performed.

By keyword regularization, keywords that have many expressions with the same meaning were unified. Rules of regularization were set manually, and by using calculation program and by following the rules, keyword regularization was performed. For example, 3 words of “car-navi”, “car navigation”, and “car-navi system” were unified into an expression “car navigation system”.

In keyword decomposition, keywords that have multiple meanings were decomposed. Decomposition rules were created manually, and by using calculation software and by following the rules, the keyword decomposition was performed. For example, keyword “3D CAD” was broken down into 2 words “3D” and “CAD”.

Words that were unsuitable as a keyword were deleted from the keyword list.

The list of optimized keywords from b) and the index produced from c) was grouped together in order to make a new keyword list.

To the keywords that were grouped in d), same optimization process from b) was performed again.

4. 분류 및 문헌조회의 도구

In this analysis, classification of documents based on the extracted keywords is performed. The classification was done in terms of construction field and business phase. Documents of construction field were classified under 20 categories such as roads and underground structures, and documents of business phase were classified under 10 categories such as investigation and planning, summary and detailed design – total of 200 categories were used to classify the documents. Next, for each of the documents, sorting number of classified category was assigned. Number of documents and document sorting number of construction field / business phase are as shown in Table 2.

There is a case when the number of document is none or extremely small under a category. Therefore, by only extracting category with more than 5 documents, investigation is done on 10% of the total 200 categories. Headings that have more than 5 documents were placed on a spreadsheet.

After classifying the documents, analyses on relatedness of construction field / business phase and on documents related to 3D information were performed.

“Analysis on number of documents in terms of construction field”, “analysis on number of documents in terms of business phase”, and “analysis on number of documents in terms of construction field / business level” were performed. Each analysis is explained below.
### Table 2  Document Count and Document Sorting Number for Each Category

<table>
<thead>
<tr>
<th>Construction Field</th>
<th>Business Phase</th>
<th>Investigation and Planning</th>
<th>Summary and Detailed Design</th>
<th>Addition</th>
<th>Construction</th>
<th>Investigation and Planning</th>
<th>Summary and Detailed Design</th>
<th>Addition</th>
<th>Construction</th>
<th>Disaster Prevention</th>
<th>Lifecycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roads</td>
<td>A</td>
<td>A1 13 A2 10 A3 1 A4 5 A5 3 A6 1 A7 0 A8 1 A9 1 A10 0</td>
<td></td>
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<tr>
<td>Underground Structures</td>
<td>B</td>
<td>B1 2 B2 0 B3 1 B4 0 B5 0 B6 0 B7 0 B8 0 B9 0 B10 0</td>
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<tr>
<td>Basement Pergolas</td>
<td>C</td>
<td>C1 0 C2 0 C3 0 C4 0 C5 0 C6 0 C7 0 C8 0 C9 0 C10 0</td>
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<tr>
<td>Tunnel Structures</td>
<td>D</td>
<td>D1 0 D2 1 D3 0 D4 0 D5 0 D6 0 D7 0 D8 0 D9 0 D10 0</td>
<td></td>
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<tr>
<td>Bridges</td>
<td>E</td>
<td>E1 0 E2 0 E3 0 E4 0 E5 0 E6 0 E7 0 E8 0 E9 0 E10 0</td>
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<tr>
<td>Water Structures</td>
<td>F</td>
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<tr>
<td>Coast Structures</td>
<td>G</td>
<td>G1 2 G2 1 G3 0 G4 1 G5 3 G6 0 G7 0 G8 0 G9 0 G10 0</td>
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<tr>
<td>Preventing Sand Erosion</td>
<td>H</td>
<td>H1 0 H2 0 H3 0 H4 0 H5 0 H6 0 H7 0 H8 0 H9 0 H10 0</td>
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<tr>
<td>Dam Structures</td>
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<tr>
<td>Urban</td>
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<tr>
<td>Topography, Foundation,</td>
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<tr>
<td>Railways</td>
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<tr>
<td>Plant and Power Plant</td>
<td>O</td>
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<tr>
<td>Shale Tunnels</td>
<td>P</td>
<td>P1 0 P2 0 P3 0 P4 0 P5 0 P6 0 P7 0 P8 0 P9 0 P10 0</td>
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<tr>
<td>Composite Structures</td>
<td>Q</td>
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<tr>
<td>Others</td>
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</tbody>
</table>
(1) 工程项目中的3D信息应用情况及其影响

分析了不同类型的文档在施工领域的分布。结果如下图所示（图2）。图中显示，3D信息在“道路”类中占35份，“结构”类中有34份，和“城市”类中有32份。作为原因，3个类别的“道路”、“城市”和“结构”类都有很多业务案例，预期它们将有大量与3D信息相关的文档。此外，这些3个类别的内容是基本的施工行业。因此，使用3D信息正在从基本的施工领域扩展。

其次，数字的大小表明了“桥梁”、“建筑/电力相关”以及“复合结构材料”，可以理解为3D信息也在复杂结构材料中被广泛使用。在其他施工领域，3D信息的应用程度不如上述领域。它被理解为3D信息在施工领域中被广泛使用的一个重要因素。

(2) 工程项目中的3D信息应用情况及其影响

分析了不同类型的文档在施工领域中的业务阶段分布情况，结果如下图所示（图3）。

在雷达图中，可以看到“施工”和“调查/规划”类别的文档数量相对较大，分别为65和58份。从这些类别中，我们可以看出3D信息在“城市”和“城市/调查和规划”中的应用情况。

在这一分析中，3D信息在分类为施工领域/业务阶段的项目中被广泛应用于“施工”和“调查/规划”阶段。使用3D信息的CAD数据是原因，3D信息的使用情况在施工阶段“调查/规划”和“施工”中广泛使用。

为了推广施工CALS/EC，需要在每个业务阶段进行信息交换、协作、共享和重用。在这一分析中，可以观察到每个业务阶段使用3D信息的数量和影响关系。其中，施工领域/业务阶段的3D信息应用情况的3D图示（图4）。同时，一个3D图示（图5），仅显示了分类中超过5个文档的类别。

“城市/调查和规划”类，17个文档，最多文档数的类别，与3D信息相关的文档。下图是“结构/施工”类的15个文档数和“道路/调查和规划”类的13个文档数。
Fig. 4 Number of Documents for Each Category of Construction Field / Business Phase

Fig. 5 Number of Documents on Each Category of Construction Field / Business Phase (More Than 5 Counts)
provide visual presentation of the road plans for the residents. It is believed that the use of CAD and CG in the construction industry is essential for explaining construction plans to the residents.

(3) 예상치 못한 특성

In this category, it can be seen that there are a lot of cases of use of 3D information in expressways, as there is keyword “highway” on all of the documents. Because there are a lot of keywords of “soil filling” and “cut / fill volume”, it can be suspected that 3D information is effectively used in calculation and management of cut / fill volume in the highway construction business.

(4) 예상치 못한 특성

In this category, there are a lot of keywords, such as “structural design”, “reinforced concrete structures”, and “steel structures”, which are related to bridges. From the existence of keywords such as “product model” and “modeling”, it can be said that 3D information is used in bridge modeling.

(5) 예상치 못한 특성

In this category, keywords such as “CG”, “urban view”, “simulation”, and “virtual reality” have the highest frequencies among the group. From this, it can be thought that visualization of urban plans is being performed by expressing them in CG and by using simulation and virtual reality.

(6) 예상치 못한 특성

In this category, keywords related to disaster prevention held the top ranks. From the fact that there is keyword of “simulation”, it can be understood that 3D simulation of disaster prevention is being performed. Also, because there are a lot of keywords that are related to ground conditions and earthquakes, it can be understood that there are great deal of emphasis especially on earthquakes, among the field of disaster prevention.

(7) 예상치 못한 특성

In this category, because there is keyword of “2D”, it can be said that system that integrated 2D / 3D is being used. It can also be thought that CG modeling is being used in structural design phase.
<table>
<thead>
<tr>
<th>Table 3</th>
<th>Keyword Frequencies</th>
</tr>
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</table>
This category, it can be recognized that 3D information is being effectively used in construction of structures, because there are keywords of “structural construction” and “construction planning”. Also, presence of the keyword “building design” shows that 3D information is being used in building design.

In this category, frequencies are high in keywords such as “CG” and “DTM”. From this, it can be understood that investigation and planning are being executed by using CD and DTM, in the field related to topography, foundation, and mountain. It can also be stated that utilization of remote sensing technology is expanding.

In this category, because the keyword “land development” is found in half of the documents, it can be understood that 3D information is being used in land development with consideration of disaster prevention. Also, from the fact that there are a lot of keywords related to earthquakes, it can be speculated that there is high interest especially in earthquakes in this category.

In this category, because frequencies are high on keywords such as “product model” and “modeling”, it can be understood that 3D information is being used in modeling in plant / power plant related work. Because plant / power plant is complicated structure, it is thought that 3D expression is in demand.

In this category, there are keywords “database” and “pipeline design”, and it can be understood that the use of database is advancing. Also, it can be suspected that 3D information is especially used in pipeline design.

In this category, frequencies of keywords “simulation” and “virtual reality” are high. From this, it can be said that visualization of construction of plant and power plant is being performed by using simulation and virtual reality.

In this category, there are keywords “photogrammetry”, “topographical map”, and “map production”. From this, it can be understood that photogrammetry is being used in topographical map and in map production.

Because there are keywords “GPS” and “laser scanners”, it can be understood that construction of 3D information is being performed by using GPS and laser scanner in construction of composite structures.

In this category, “underground structures” is the keyword for half of the documents. From this, it can be said that 3D information is being used in expression of extremely graphically complicated underground structures. It can also be said that 3D disaster prevention simulation is being performed.

In this category, because there are keywords “digital image”, “photogrammetry”, and “CG”, it can be known that digital image acquired from photogrammetry is being expressed in 3D in investigation / planning phase.

In this category, frequencies are high in keywords of “simulation” and “CG”, and it can be known that simulation is being performed by using CG in the construction phase. In addition, from the keyword “animation”, it can be thought that 3D CG is being expressed as an animation.

In this category, because frequencies are high in keywords such as “virtual reality” and “CG”, it can be understood that technology in each of the lifecycle field is gaining attention. From this, it can be thought that in lifecycle process, information for exchange, collaboration, sharing, and reuse is being transformed three-dimensionally.
In this research, documents related to the application of 3D information in the construction industry were investigated. Keywords were extracted from 282 documents. In addition, documents were classified in terms of construction field and business phase based on the keywords.

To the classified documents, “analysis of number of documents in terms of construction field / business phase” and “keyword frequency analysis in terms of construction field / business phase” were performed.

In “analysis of number of documents in terms of construction field / business phase”, 3 types of analysis were performed: “analysis of number of documents in terms of construction field”, “analysis of number of documents in terms of business phase”, and “analysis of number of documents in terms of construction field / business phase”.

In these 3 types of analyses, we were able to grasp the current circumstance of practical application of 3D information in the construction industry. In construction field and business phase that use 3D information, it can be thought that process of construction CALS/EC is being assertively implemented. It is believed that in the future, information exchange, collaboration, sharing, and reuse of entire life-cycle will be smoothly proceeded by continuous use of 3D information in each construction field and business phase.

In “analysis of keyword frequencies in terms of construction field / business phase”, analysis of keyword frequencies in each category was performed. By analyzing keyword frequencies, we were able to grasp the type of technology and the field that the 3D information is being used for each construction field and business phase.

In order to develop the construction industry for the next generation, it will be important to effectively utilize 3D information. In this research, document investigation was performed in order to grasp the current situation on practical application of 3D information in the construction industry.

From this present research, construction fields and business phases in which 3D information is being used were clearly expressed on charts and diagrams. In addition, by analyzing keyword frequency for each document, we were able to grasp how the 3D information was being used.

Result of this present research is believed to be an extremely useful information for engineers and technologists who are attempting to apply 3D information for introduction of construction CALS/EC. In the future, by periodically performing the document investigation in the same way, we would like to grasp the expansion of the use of 3D information. In addition, we would like to contrive development that will further make this research a better use for the professionals in the construction industry.

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