Verification of National Digital Twin Standard for Buildings (Study case: Korea)

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Key words: Digital twin, Standards, Buildings, ISO, OGC, CityGML

SUMMARY

The digital twin, a key technology in the fourth industrial revolution, is to predict results in advance by creating twins of real things in the digital space and simulating situations that may occur in real life. In this regard, in Korea, national digital twin projects are actively being promoted to build real-world land in the virtual world. The Korean government has established national standards based on geographic information standards to get interoperability of national digital twin data. The standards were developed a reference model standard first for establishing a sharing system of Korean national digital twin, and then profiled and expanded based on various standards of OGC, such as OGC CityGML 3.0, to define a data model of Korean national digital twin for each major domains of the country. The data quality, metadata, and data product specification standards of each domains were developed by profiling ISO 19109, 19131, 19157, which are the fundamental standards for geographic information, centering on the data model defined as Korean standards.

In order to secure the usability of national standards, this study aims to analyze national digital twin data built for building domains and to present examples modeled to standards. Sample data is composed of three: an UML diagram, a XML schema, and a GML, and was produced according to the data construction flow based on a use case for administrative service called "Computation service of Building permit areas"

First, a UML diagram was drawn to suit the purpose and requirements of data construction based on the national standard of the building data model. Then the geometry, sementic, properties information of building’s feature catalogue were written as XML schema of the Korean national digital twin for building data model based on the CityGML 3.0 schema. Finally, according to the XML schema, three-dimensional building data was encoded into GML.

This case is an implementation case of Korean standards based on OGC City GML 3.0, and it is hoped that it will be meaningfully used for data implementation based on standards. Also it is expected that this case will be a cornerstone internationally in strengthening the utilization of geographic information standards in the future.

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1. INTRODUCTION

The digital twin is defined as a system that builds and connects the same object as an object existing in the physical space of a digital space to monitor, analyze, simulate, predict, and provide related information through an object in a digital space. These digital twins can be used to identify various phenomena and problems in physical space and find solutions through digital space.

In order to analyze various spatial information and phenomena such as roads and underground facilities, transportation, climate, and buildings by constructing a digital twin, it is necessary to collect a lot of data and select whether it is necessary for construction. This process takes a lot of budget and time, which lowers the efficiency of the work. In order to solve this inconvenience, a solution that can secure interoperability between data is needed, and the application of standards for constructing geospatial information data is an example.

Domestic standards related to the construction of digital twin building data include

- KS X 6808-1 Geographic Information – National Digital Twin Building – Part 1: Data Model(2022)
- KS X 6808-2 Geographic Information – National Digital Twin Building – Part 2: Data Quality(2022)
- KS X 6808-3 Geographic Information – National Digital Twin Building – Part 3: Metadata(2022)
- KS X 6808-4 Geographic Information – National Digital Twin Buildings – Part 4: Data Product Specification(2022)
- OGC City Geoprahy Markup Language(CityGML) Part 1: Conceptual Model Standard(2021)

KS X 6808-1 and OGC CityGML 3.0 were standards for data modeling, KS X 6808-1 profiled ISO 1913, 19107, 19109, KS X 6808-2 profiled ISO 19157, KS X 6808-3 profiled ISO 19115-1 for metadata definition, and KS X 6808-4 profiled ISO 19131 for data requirement definition.

In this study, the above standards are applied to produce product specifications and construct empirical data including UML, XML schema, and GML necessary for building data, and a data verification checklist is derived accordingly.

2. Building Data Construction Methodology

2.1 Building Data Product Specification

The digital twin product specification aims to acquire consistent data and support digital twin services when constructing digital twin data. The product specification can define the requirements required for data construction. The product specification consists of 12 categories such as outline, scope, data identification, data content and structure, reference system, data quality, maintenance, data product distribution, and metadata.

Table 1 Building Data Product Specification

Category	Main Content
1. Overview	Define the information needed to understand the product specification
2. Scope of Specifications	Define information about the level of the target described by the product specification
3. Data identification	Define data requirements that are distinct from other data, such as the purpose, purpose, and scope of construction of building data
4. Data content and structure	Define the structure and content requirements of the data that building data should have using data models (UML) and topographical lists
5. Reference system	Define reference system requirements to know the absolute coordinates of building data
6. Data Qualification	Defining requirements such as quality evaluation items and evaluation methods, inspection standards, and delivery methods of evaluation results to ensure the quality of building data
7. Maintenance and Management	Define future maintenance requirements for building data
8. Data product distribution	Define the type and format requirements of relevant outputs to be delivered for utilization of building data
9. Metadata	Define requirements for providing metadata information necessary to understand building data

2.2 Data Configuration for Empirical Use

2.2.1 CityGML

CityGML is a standard developed by OGC based on the spatial object model defined by SIG3D (Special Interest Group for 3D), a three-dimensional spatial object research group in Germany, and CityGML 1.0 was established in 2008 and is currently in use.
CityGML is an open concept model for the storage and exchange of 3D urban models, with the aim of enabling the efficient construction, sustainable maintenance, and reuse of the same

data in various applications by commonly defining the basic entities, attributes, and relationships of 3D urban models.
CityGML introduces the concept of Level of Details (LoD), but in version 3.0, it is divided into four stages from 0 to 3. LoD 0 expresses building and indoor space in a plane that is not perpendicular through a footprint or multiple layers of each floor. LoD 1 is divided into Building and Building Part, and is expressed as a three-dimensional with a unique height and volume. LoD 2 is expressed as a three-dimensional with a roof shape, and additional structures such as doors and windows are also expressed. LoD 3 expresses the external expression as an architectural model at a level most similar to that of a real-world building.
In this study, data is constructed by selecting the fineness according to the data identification requirements of the building data product specification, such as the type and shape of the target building.

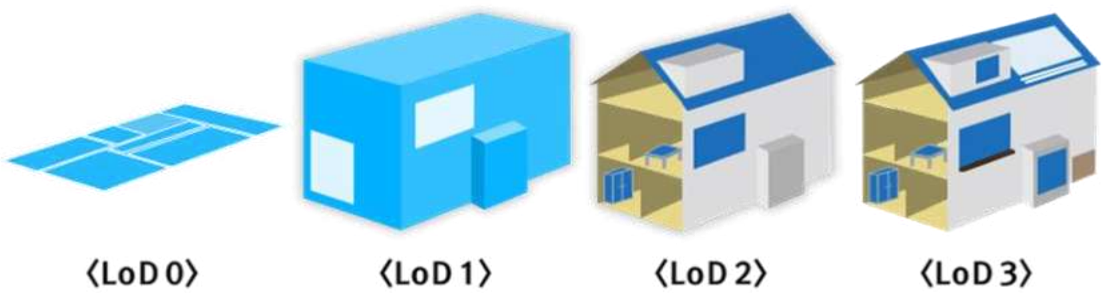


Figure 1 CityGML 3.0 LoD

2.2.2 UML(Unified Modeling Language) Data Model

UML is an integrated modeling language created by OMG (Open Management Group), an object-related standardization organization, in November 1997 by combining object modeling technology and OOSE methodology, and is a language for communication between developers in the process of demand analysis, system design, and system implementation through eight diagrams such as use case diagrams and class diagrams.

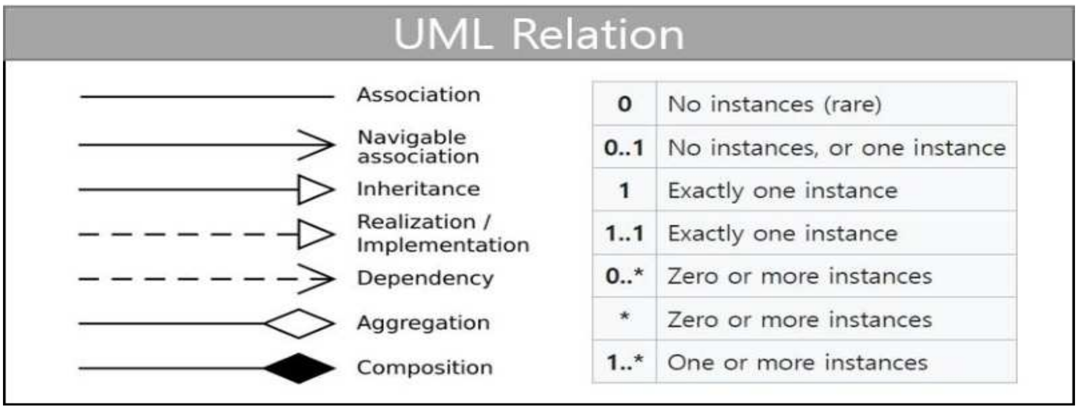


Figure 2 UML Class Diagram

The building data to be built should present the data structure to reflect the characteristics of the real world building, and to define the topography of the building data to be built, information such as geometry and location information, semantic information, and attribute information should be included. It describes the data content and structure using the UML data modeling language.
In addition, this study applied a method of designing a data model through Application Domain Extensions (ADE), which presents a common data model and expands the data model as needed. ADE is a method of introducing additional attributes to the CityGML data model.

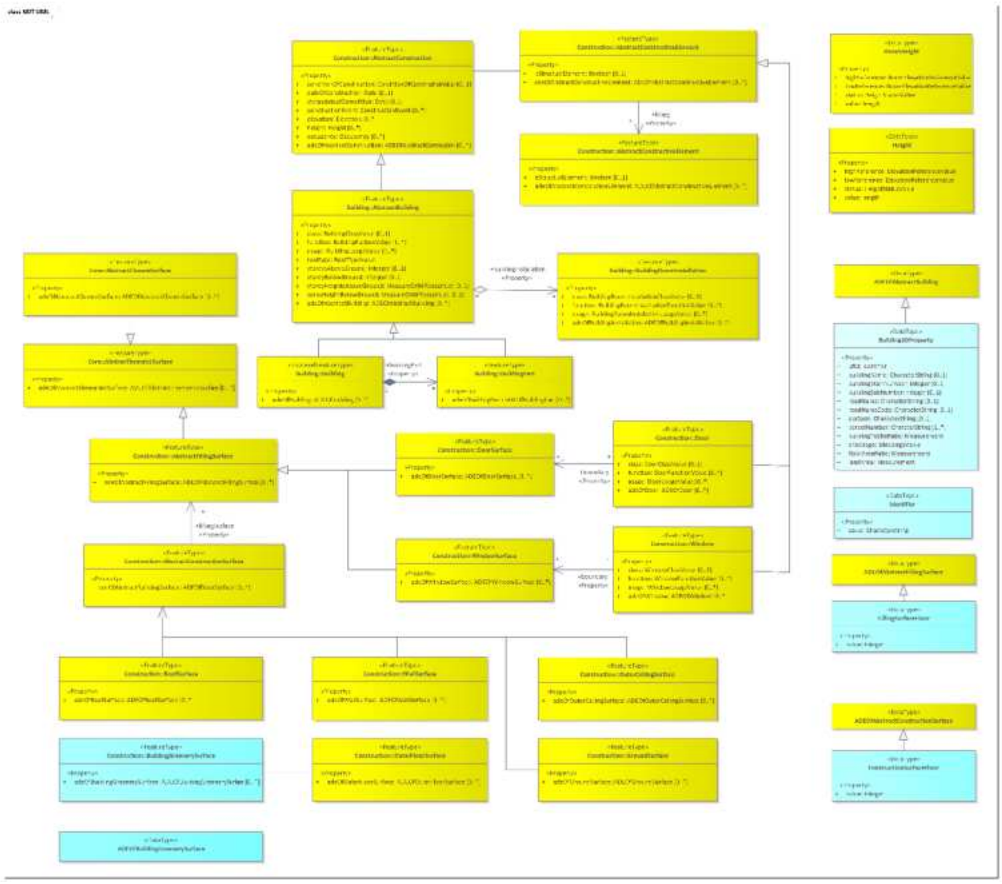


Figure 3 UML Diagram for Building data reperesntation

2.2.3 XML Schema

The XML schema is used when presenting structured criteria so that the data content and structure of the data model can be calculated in XML format, and is used to convert the constructed shape data into GML. The GML data converted using the XML schema is structured so that attribute information can be inserted. In this study, we present an XML schema structured according to XML grammar of the UML data model expanded and defined above.

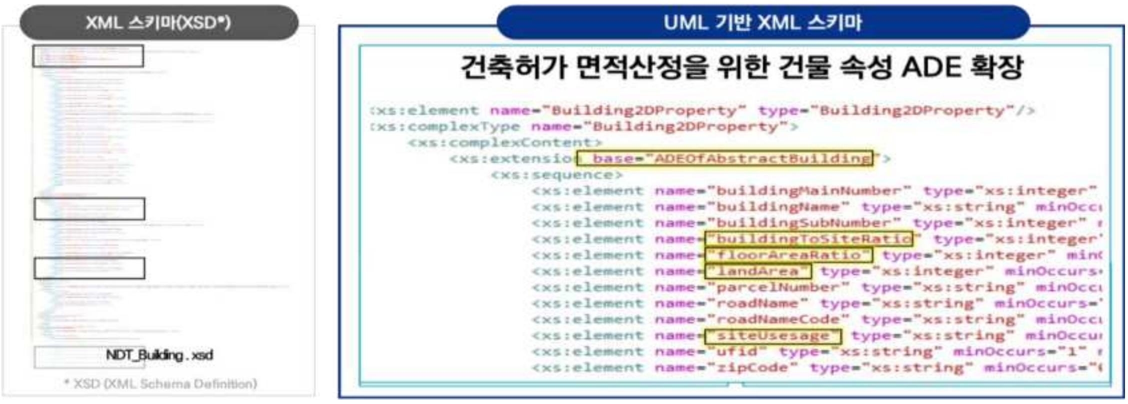


Figure 4 XML for Property Information Extension(example)

In addition, a list of attribute codes referenced in the data model was created in XML format so that it could be referenced when producing GML data using the XML schema.

Figure 5 XML in the attribute codelist(example)

2.2.4 GML(Geography Markup Language) Data

GML data is data including shape information, semantic information, and attribute information constructed using the collected data, and the purpose of the GML data presented in this study is to identify and compare the converted GML calculation form using the XML schema.

In Semantic, the 'ground surface', 'wall surface', and 'Roof surface' of the building are identified.

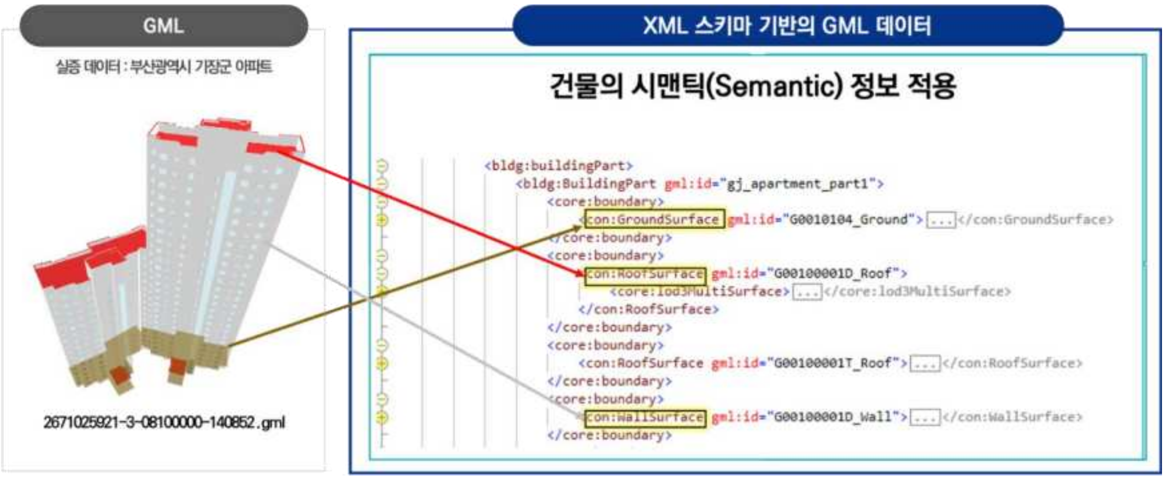


Figure 6 Semantic information represntation of GML(example)

The attribute information includes the attribute information of the building extended by the ADE method, and the code value is inserted by referring to the codelist XML.

Figure 7 Representing property information in GML data(example)

3. Data Verification System

3.1 Configuring a Data Verification System

In the process of producing and managing data, data producers and managers need a verification system to ensure quality and interoperability so that data can be selected and used according to the requirements of data users by explaining data quality. In the data verification

system, factor definitions for quality verification of output data and standard suitability evaluation items of standard outputs are defined.
It is verified based on the building data product specification, and a checklist for standard suitability verification is derived. The standard suitability checklist is used to verify the standard suitability of standard outcomes, and there are three outcomes: product specifications, quality evaluation result reports, and metadata statements.
Building product specifications conduct standard conformity verification at the standard application planning stage prior to data construction, and quality evaluation result reports and metadata statements conduct standard conformity review after data construction is completed.
The quality of constructed building data can be evaluated and results can be organized through the data quality evaluation elements presented in the data verification system. As for the data quality verification element, the definition of the quality verification element and the evaluation method, procedure, and standard for each verification element were presented based on quality-related standards such as KS X 6808-2 and KS X ISO 19157.

Table 2 Data Verification

Standard	Verification contents	Subject to verification
KS X 6808-4 Geographic Information – National Digital Twin Building – Part 4: Data Product Specification	Standard Conformity of standard results	Standard result (Building Data Product Specification)
KS X 6808-1 Geographic Information – National Digital Twin Building – Part 1: Data Model	Standard Conformity of Data Models	Data model(UML) (Building Data Product Specification)
	Standard Conformity of standard results	Standard result (Building Feature Category)
	Standard Conformity of XML Schema	XML Schema
	Standard conformity of building data	Building data(GML)
KS X 6808-2 Geographic Information – National Digital Twin Building – Part 2: Data Quality	Standard conformity of building data	Standard result (Building Data Quality Assessment Results Report)
KS X 6808-3 Geographic Information – National Digital Twin Building – Part 3: Metadata	Standard Conformity of standard results	Standard result (Building Metadata Statement)

3.2 Building Data Quality Assessment

The quality evaluation of building data is carried out in five stages in the order of evaluation preparation, evaluation factor designation, evaluation method designation, evaluation criteria selection, and evaluation results.

3.2.1 Preparing for Data Quality Assessment

Before evaluating data quality, prepare by specifying the range of data to be secured and the quality factors to be evaluated, and preparing the characteristics and detailed descriptions of the data. The data range includes a description of the general characteristics of the data subject to quality evaluation and the temporal and spatial ranges, and the quality evaluation factor selects the elements to explain the data quality.

3.2.2 Preparing for Data Quality Assessment

Data quality is explained through a measurement list of quality factors selected in the data quality evaluation preparation process. The evaluation factors follow the 16 items specified in KS X 6808-2 Geographic Information – National Digital Twin Building - Part 2: Data Quality.

구분	품질 요소	세부요소	세세부요소	품질 측정 기준	평가 범위
001	완전성	초과	대상객체 초과	대상객체 초과 항목의 비율	데이터세트
002		누락	대상객체 누락	대상객체 누락 항목의 비율	데이터세트
003	논리적 일관성	개념 일관성	건물 데이터 모델 스키마 준수	데이터 모델 스키마 준수 여부	데이터세트
004		위상 일관성	2차원 구조화 일관성	2차원 기하 및 위상 제약조건을 준수하지 않는 항목 수	부분 집합
005			3차원 구조화 일관성	3차원 기하 및 위상 제약조건을 준수하지 않는 항목 수	부분 집합
006	위치 정확성	절대적(외부) 정확성	2차원 위치정보 정확성	면적 측정의 제곱평균 오류	데이터세트
007			3차원 위치정보 정확성	수직 위치 정확도의 제곱 평균 오류	부분 집합
008			기하학적 충실도	디지털 트윈국토 건물의 기하학 형태 (형상, 유형 등) 충실도 여부	부분 집합
009		상대적(내부) 정확성	건물 구성요소의 위치 정확성	건물 구성요소의 상대 위치 정확도 여부	부분 집합
010	주제 정확성	분류 정확성	시맨틱 항목 분류 정확성	기하와 시맨틱 항목의 오분류 비율	부분 집합
011		속성 정확성	속성 내용 불일치	부정확한 속성값의 비율	부분 집합
012			속성 내용 누락	유의 수준 내 기하와 속성정보 간의 불확실성	부분 집합
013	시간 품질	시간 측정의 정확성	변화 이력 정보 정확성	유의 수준 내 시간 값과 층적 값 간의 불확실성	부분 집합
014		시간 일관성	변화 이력 정보 관리	변화에 따라 시간 속성의 기록 및 관리에 대한 일관성 여부	부분 집합
015		시간 유효성	변화 시간 유효성	정의된 규칙의 시간과 관련된 데이터의 유효성 여부	부분 집합
016	유용성	관리파일 작성오류	메타데이터 정의 및 관리	제품 사양 범위 내에 품질 결과 제공 여부	데이터세트

Figure 8 National Digital Twin Building Quality Evaluation Elements

It is possible to designate a data quality evaluation method and explain it appropriately, evaluate data according to the procedure, and apply one or more evaluation methods for each data.

2.7 위치 정확성 – 절대적(외부) 정확성 – 3차원 위치정보 정확성

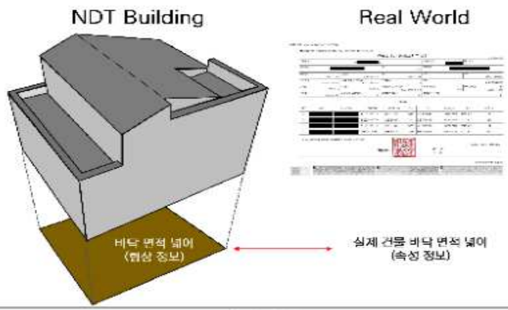
측정항목 정보 NDT_BLDG::DQ_Measure		
측정 식별자	측정항목의 측정 식별자	007
이름	측정항목의 세세부요소명	3차원 위치정보 정확성
데이터 품질 요소	측정항목의 품질 요소명	위치 정확성
데이터 품질 하위 요소	측정항목의 세부요소명	절대적(외부) 정확성
데이터 품질 기본 측정	품질 기본 측정 방법	해당사항 없음
정의	데이터 품질 기본 측정의 정의	수직 위치 정확도로써 건물 데이터의 수직높이 값과 실제 건물 높이 값 간의 차이
설명	데이터 품질 기본 측정의 설명	건물의 수직적 높이 값의 절대적 위치 정확도를 실제 건물의 높이 값과 비교하여 허용오차(torrelance) 기준을 설정하여 평가한다. 
평가 범위	품질 평가의 범위	지형지물
보고 범위	품질 측정 보고의 범위	데이터세트
매개변수	데이터 품질 파라미터	해당사항 없음
데이터 품질 값 유형	데이터 측정 결과를 보고하는 데 사용하는 데이터 유형	측정
데이터 품질 값 구조	데이터 품질 파라미터의 구조	해당사항 없음

Figure 9 Building Data Quality Assessment Facotrs(example)

3.2.3 Specify Quality Assessment Method

Detailed information on evaluation methods for each of the 16 evaluation factors is described in Appendix 5. Report on Building Data Quality Evaluation Results (Form) of KS X 6808-2 Standard, and evaluation procedures and judgment criteria are presented.

3.9 위치 정확성 – 상대적(내부) 정확성 – 건물 구성요소의 위치 정확성

품질 평가 방법 정보 NDT_BLDG::DQ_EvaluationMethod			
평가방법코드	NDT_BLDG_DQ009_001		
평가방법유형 .evaluationMethodType	**직접** 수동평가 – **내부** 표본평가(directInternal : 직접 내부)		
데이터 품질 기본 측정	LE95		
판정 기준	데이터의 건물 구성 요소간 상대적 길이 값과 실제 건물 구성 요소간 상대적 길이 값의 차이 RMSE(평균 제곱근 오차)가 1.965 미만		
평가절차 .evaluationProcedure	평가 항목 설정 → ① 건물의 최고 높이 비교 ↓ 표본 개수 설정 → 전수 검사 이므로 해당 사항 없음 ↓ 표본 추출 → 전수 검사 이므로 해당 사항 없음 ↓ 평가 → 평가 항목별 평가 (하단 평가방법설명 참조)		
평가방법설명 .evaluationMethodDescription	**① 건물의 최고 높이 비교** - 표본으로 추출된 30개의 건물별로 건물 데이터(GML)의 '건물 바닥(GroundSurface)'부터 건물의 가장 높은 구조물까지의 높이를 계산한다. (a_i) - 표본으로 추출된 30개의 건물 데이터의 건축물 대장 및 건축 도면에서 '건물 바닥'으로부터 건물의 가장 높은 구조물까지의 높이 값을 식별한다. (b_i) - 표본으로 추출된 30개의 건물 데이터의 계산 값과 참 값의 차이를 활용해 평균 제곱근 오차(RMSE)를 계산한다. (RMSE $= \sqrt{\frac{1}{30}\sum_{i=1}^{30}(a_i - b_i)^2}$) - 계산한 평균 제곱근 오차(RMSE)가 1.965 미만일 경우, "PASS"를 판정한다. - 그 이외의 경우, "FAIL"을 판정한다.		
참조문서 .referenceDoc	문서 유형	건물 제품사양서	
	일자	일자	0000 – 00 – 00
		일자 유형	016 : 배포

Figure 10 Building Data Quality Assessment Method

According to the table above, the criterion for judgment is a confidence level of 95% (significance level of 5%), and the significance level value is calculated using RMSE (mean square error). Direct evaluation of the evaluation method type refers to an evaluation method that inspects items within a dataset.

3.2.4 Selection of Quality Assessment Criteria

Evaluation criteria are needed to determine data quality assessment results. In this study, the 'Application Scope and Acceptance Criteria of Quality Factors by 3D Land Spatial Information Quality Inspection Method' of the '3D Spatial Information Construction Work Regulations' were referred to in accordance with the domestic situation.

Quality Factor	Quality Assessment Factor	Evaluation method		Evaluation target / sample application	Evaluation criteria (Criteria for passing)
		Automatic	Manual		
completeness	Target Object Exceeded		●	Dataset / Total Assessment	Error rate 0%
	Missing target object		●	Dataset / Total Assessment	Error rate 0%
logical consistency	Building Data Model Schema Compliance		●	Dataset / Total Assessment	No error
	2D Structured Consistency		●	Dataset / Total Assessment	Error rate less than 5%
	3D Structured Consistency		●	Dataset / Total Assessment	Error rate less than 5%
Position accuracy	2D Location Information Accuracy	●		feature / sample evaluation	Significance level less than 5% (less than RMSE 1.965)
	3D Location Information Accuracy	●		feature / sample evaluation	Significance level less than 5% (less than RMSE 1.965)
	geometric fidelity		●	feature / Total Assessment	Error rate less than 5%
	Location accuracy of building components		●	feature / sample evaluation	Significance level less than 5% (less than RMSE 1.965)
subject accuracy	semantic category classification accuracy		●	feature / Total Assessment	Error rate less than 5%
	Property Content Mismatch		●	feature / Total Assessment	Error rate less than 5%
	Missing property content		●	feature / Total Assessment	Error rate less than 5%
Time quality	Change History information accuracy		●	feature / Total Assessment	No error
	Manage change history Information		●	feature / Total Assessment	No error
	Change Time Validity		●	feature / Total Assessment	No error
utility	Define and manage metadata		●	Building Metadata Statement / Total Evaluation	No error

Figure 11 Quality Assessment Criterion

3.2.5 Quality Assessment Result

After performing data quality evaluation, the results of data quality are finally explained through quality reporting.

Quality factor	Quality Assessment Factors	Measurement result value	Evaluation criteria (Criteria for passing)	the results of the evaluation
Completeness	Target Object Exceeded	Error rate 0%	Error rate 0%	PASS
	Missing target object	Error rate 0%	Error rate 0%	PASS
Logical consistency	Building Data Model Schema Compliance	No error	No error	PASS
	2D Structured Consistency	Error rate 0%	Error rate less than 5%	PASS
	3D Structured Consistency	Error rate 0%	Error rate less than 5%	PASS
Position accuracy	2D Location Information Accuracy	RMSE 1.5	Significance level less than 5% (less than RMSE 1.965)	PASS
	3D Location Information Accuracy	RMSE 1.5	Significance level less than 5% (less than RMSE 1.965)	PASS
	Geometric Fidelity	Error rate 0%	Error rate less than 5%	PASS
	Location accuracy of Building components	RMSE 1.5	Significance level less than 5% (less than RMSE 1.965)	PASS
Subject accuracy	Semantic category classification accuracy	Error rate 0%	Error rate less than 5%	PASS
	Property Content Mismatch	Error rate 0%	Error rate less than 5%	PASS
	Missing property content	Error rate 0%	Error rate less than 5%	PASS
Time quality	Change History information a ccuracy	No error	No error	PASS
	Manage change history Information	No error	No error	PASS
	Change Time Validity	No error	No error	PASS
Utility	Define and manage Metadata	No error	No error	PASS

Figure 12 Quality Assessment Result(example)

Reference document		Explanation
Building product specification		Includes data requirements information such as number of buildings, LoD levels. Etc
List of Building features		Include shape information, semantic information, and attribute Information
Building Metadata Statement		Include building metadata information
Building Data Quality Assessment Results Report		Includes quality assessment items, assessment methods, and assessment criteria (pass criteria) information
Quality assessment procedures		**Explanation**
Evaluation Item setting	Specify data quality unit	Composed of scope and quality factors - **Range:** Specify general features, space, and time ranges that identify the data being evaluated for quality - **Quality Factors:** Components that describe some of the data quality (Completeness, logical consistency, location accuracy, subject accuracy)
	Specify data quality measurement	Specify Quality Assessment Factors (16 types) Refer to 'Appendix 5. building data quality assessment result report'
	Specify the method of evaluation	Specify quality assessment methods (16 types) Refer to 'Appendix 5. building data quality assessment result report'
Sample Extraction		Setting the number of samples - Set at least 30 samples for the sample to represent the population and for the application of normal distribution Sampling - Simple Randomized Extraction
Quality Assessment		
Data Quality Reporting		- Metadata - Quality report Refer to 'Appendix 5. building data quality assessment result report'

Figure 13 The overall structure of National Digital Twin building data quality assessment

3.3 Standard Conformity Review Checklist

A standard conformity implementation specification and checklist were produced for standard conformity evaluation by referring to the 'mandatory/condition' items and data types of data items defined in the four digital twin national land building standards. The checklist is composed of review items and detailed review items, and can be checked by indicating whether or not mandatory/condition items are implemented. In addition, Ensure that the standard outcomes have implemented the items defined in the digital twin national land standards and are implemented appropriately for the data type.

[디지털 트윈국토표준 : 지리정보-디지털 트윈국토-건물 제품사양] 적합성 체크리스트						
"건물 제품 사양서"를참고하여 아래 체크리스트 문항을 읽은 후 해당하는 결과에 "O"표시 하시오.						
항목 번호	검토 항목	세부검토항목		결과		
				예	아니오	판정 불가
1	건물 제품사양 구성	1	건물 제품사양서의 공통 구성 항목 9개를 작성하였는가? - 건물 제품사양 개요 - 건물 제품사양 범위 - 건물 제품사양 식별 - 건물 제품사양 데이터 내용 및 구조 - 건물 제품사양 참조체계 - 건물 제품사양 데이터 품질 - 건물 제품사양 데이터 유지관리 - 건물 제품사양 데이터 제품 배포 - 건물 제품사양 메타데이터			
2	건물 제품사양 개요	2	제품을 설명하기 위한 정보를 포함하고 있는가? (문자열(CharacterString))			
		2.1	제목에 대한 정보를 기술하였는가? (문자열(CharacterString))			
		2.2	디지털 트윈국토건물 제품 완성일이나 계약에 정한 작성일을 기술하였는가? (YYYY-MM-DD)			
		2.3	관리부서의 연락처 정보를 기재하였는가? (KS ISO X 19115 부속서 B3.5의 코드목록)			
		2.4	사용된 언어를 기술하였는가? (문자열(CharacterString))			

Figure 14 Conformity review checklist of Building product specification

4. Conclusion

When building a digital twin country, it is necessary to separately construct and link data in various fields. If the constructed data at this time use a separate model and file structure, the interoperability between digital twin country data is deteriorated, making it difficult to expand the digital twin country in the future. The application of the digital twin country standard plays a role in securing interoperability between data by enhancing the interoperability of data built between these projects.

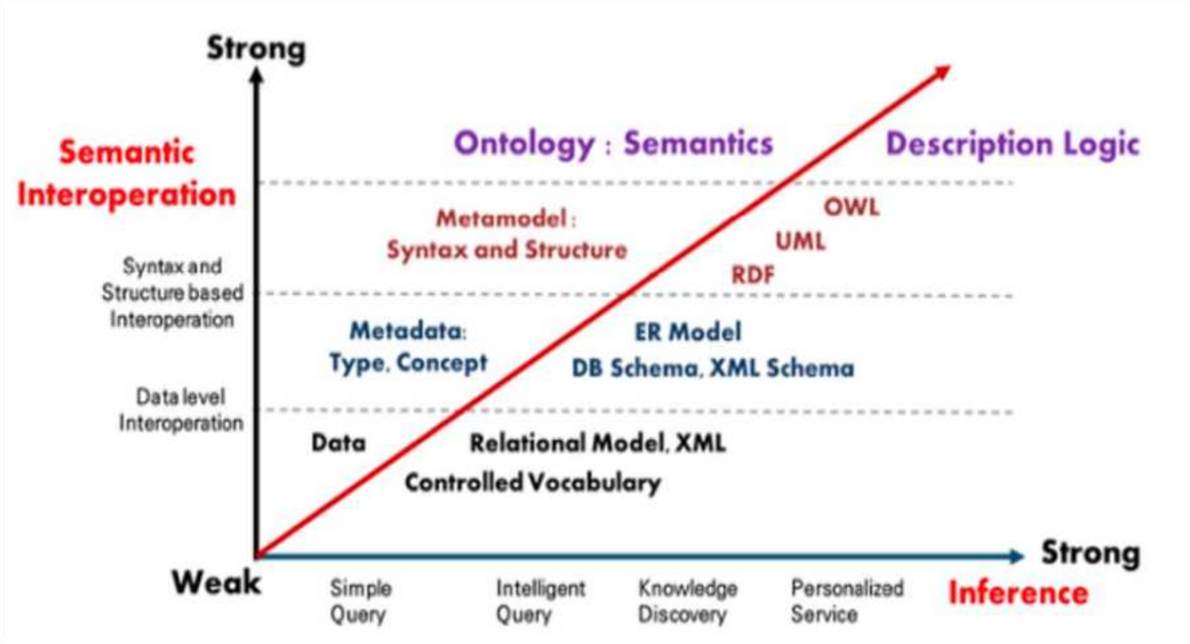


Figure 15 Interoperablility level according to Information technology language

Standards define data abstractly and conceptually for data interoperability. This role of the digital twin national land standard is to provide a common data model to secure interoperability between digital twin national land data. However, there is a difference between the standard, which is a conceptual model, and the actual object (geographic feature), and the constructed data. Since the standard defines a conceptual common model for the purpose of securing interoperability, it is necessary to define a case of applying the standard at the instance level for data construction. In order to present a standard application case and build data that has secured interoperability, it is considered necessary to present a method that can apply the standard across the project, utilize and educate it.

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BIOGRAPHICAL NOTES

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