Contextualising Ontologies with Image, Number and Rationality

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SUMMARY

Ontologies have been proven useful in areas such as information management and Artificial Intelligence. Based on ontologies, datasets using the same concepts can be integrated or converted automatically. The same concept however can represent different features depending upon perspectives. A concept "building" for instance can represent a physical building, a design building or a 3D building model and these "buildings" are related to one another based on certain logics. If one simply converts IFC to CityGML using the same concept "building" without considering the explicit representations and the logics the representations should relate, one may inappropriately use the resulted outputs as the models may have changed from design to physical and the changes involved in the life cycle are not made explicit.

The paper demonstrates a framework to contextualise ontologies based on different perspectives from I Ching, Book of Change. The perspectives are Image (象), Number (数) and Rationality (理). Image refers to the explicit representation a concept represents; Number refers to the computational models in formats that computer systems are able to process and read. Rationality means the logics things should relate. In different perspectives, the same concept can be represented differently.

As a case study, the paper illustrates how the framework can be applied in a previous research that integrates the legal space from the ePlan model and the physical space from the CityGML schema based on the LADM OWL ontology. From the different perspectives, the framework allows to check if the data is correctly integrated or converted to prevent information loss. Although the framework is conceptual, the next step is to formalise the ontologies to include the perspectives in a formal language like OWL.

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1. INTRODUCTION

In the life cycle of building data, through a conceptualisation, a design model of a building is created (see Figure 1). The model remains in the virtual world until certain approval process has been given to construct the building. From the physical construct of the building, 3D digital model can be created using mapping technique such as airborne laser scanning. Or from the same physical construct, through a building subdivision, strata boundaries may also be produced through cadastral survey.

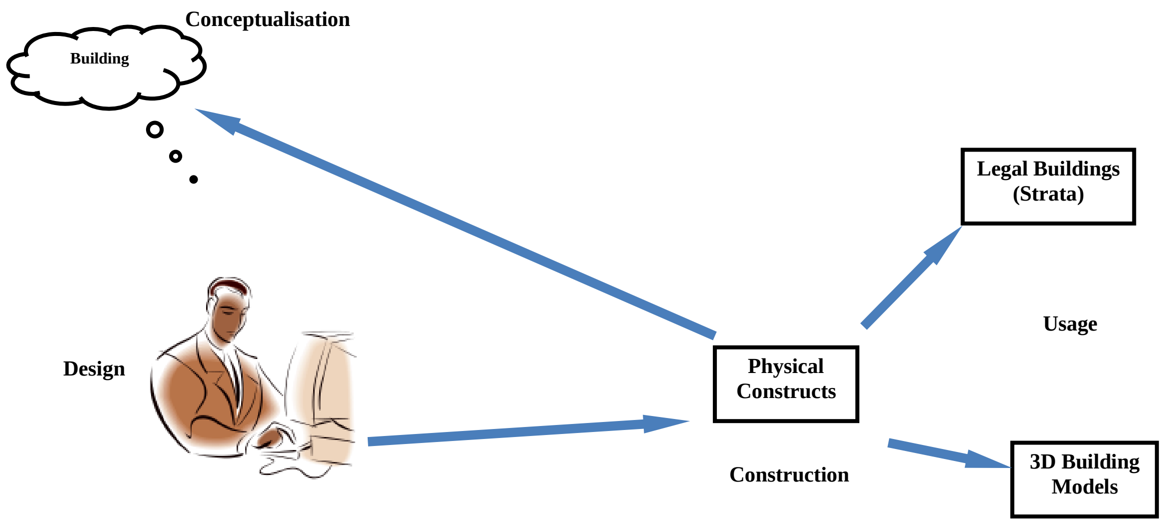


Figure 1. Life cycle of building data from conceptualisation, design, construction to usage

In this life cycle, building data have been used across different domains, e.g. architects, surveyors, GIS specialists. To efficiently manage the building data, data have been captured and stored according to certain data models. Data models have been crucial for data management and exchange formats to support data integration and to define the input and output of data exchange.

Data models are developed and maintained by different domains. The IFC data model for instance is used commonly to model the design structure of a building (El-Mekawy *et. al.*, 2012). In cadastre, the ePlan model is adopted to represent the legal aspect of a building such as the strata ownerships of the individual units within the building or the airspace and subterranean spaces (Cumerford, 2010; SLA, 2017). The CityGML data model is applied to model physical buildings (Soon and Khoo, 2017; van den Brink *et. al.*, 2013). CityGML models commonly are not referred as design models or legal imaginary objects as represented in the IFC and ePlan data models respectively.

To integrate different data models, ontologies have been used (e.g. Soon *et. al.*, 2014; Boskovic *et. al.*, 2010; Fonseca *et. al.*, 2002). However, the features the concepts represent evolve over time in the life cycle. Just making the concepts explicit in the ontologies is not sufficient to ensure data can be correctly transferred and integrated across different domains. The ontologies should be incorporated with perspectives.

In this paper, the perspectives are defined based on I Ching (Chen, 2017; Min, 2013). The perspectives are *Image* (象), *Number* (数) and *Rationality* (理). *Image* refers to the explicit representation a concept represents; *Number* refers to the computational models which computer systems are able to process and read, and *Rationality* means the logics things should relate. In different perspectives, the same concept can be represented differently.

To illustrate an example, “building” is a concept. A building can be extensionally represented as a physical construct existed in the physical world. A building can also be represented as a design model that appears on a computer screen. The physical construct and the design model are the *images* of the concept “building”. But when an IFC is converted to or integrated with CityGML model for instance, *images* of the concept “building” may have been changed. But based on ontologies, datasets using the same concepts can be integrated or converted automatically without considering if the *images* the concepts referred in the two datasets are different. This will result in information loss or using incorrect sources of input and output if the changes involved in the life cycle are not made explicit.

The paper demonstrates a framework to contextualise ontologies based on perspectives. As already shown in previous research that knowledge is pragmatic (Brodaric, 2005) and situated (Gahegan and Pike, 2006), an ontology should not be used merely based on the concepts and relationships it describes. As illustrated in this paper, an ontology should be used with perspectives to prevent the loss of information. The paper focuses on not only the explicit representations and computational models, but also the logics or truth the concepts should behave with their explicit representations. The logics can be served as integrity checks to ensure data is correctly integrated or converted. From this paper the research also hopes to shed some light on applying oriental philosophy like I Ching in the geospatial domain. The application of oriental philosophy in the geospatial domain has not much been discussed.

In what follows, Section 2 introduces *Image*, *Number* and *Rationality* as the perspectives. Section 3 elaborates how building information management is related to the three perspectives. Section 4 shows an example how the framework can be applied in a previous research. Section 5 concludes the paper.

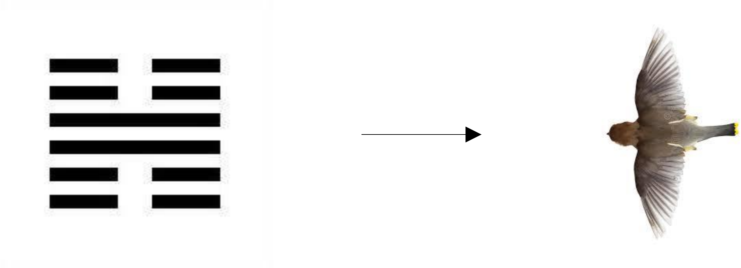
2. PERSPECTIVES FROM I CHING: *IMAGE, NUMBER* AND *RATIONALITY*

I Ching as referred by many is Book of Change. To understand I Ching, one should comprehend the following three fundamental perspectives (Min, 2013):

2.1 Image (象)

In the context of I Ching, *Image* can refer to the representation of a hexagram. For example, a hexagram as shown in Figure 2 symbolises a flying bird. The hexagram can be interpreted as like a flying bird, which can only fly in a low altitude, one is advised not to be too aggressive and should be kept in low profile when facing challenges. That is to say, the interpretation of a hexagram is related to the *image* that the hexagram represents.

In other words, *Image* refers to what is seen. In the geospatial context, this can refer to the digital models appeared on a computer screen or the physical constructs existed in the real world. The physical constructs can be natural or man-made.



small excess (小过) flying bird

Figure 2. A hexagram that has an *image* like a flying bird

2.2 Number (数)

In order to formulate a hexagram, several steps are required to follow in a certain computational manner. The order of *yao*（爻）(or line) in a hexagram also represents specific meaning. The first line or *yao* from the bottom of a hexagram indicates the foundation of a change; the second line means sprouting which indicates the formation; the third line indicates the concretising stage of a change; the fourth indicates the strong growth of change (like the leaves of a tree); the fifth signifies flourishing stage and the sixth or the top line is the fullness of change, which also implies a transformation into another circle (Chen, 2009).

It is said that the binary codes of 1 and 0, which were originated from Leibniz and have been used in the modern computer processing for decades, were adopted from I Ching's *yin* and *yan* (Zhang, 2014). So in relation to the geospatial domain, all digital resources, be it files, 3D models, data schemas, vector or raster can be referred as *Number* so long as the resource can be read and processed by a computer or a machine.

2.3 Rationality (理)

In I Ching, each *yao* has different interpretations and these interpretations are unique and form the truth of I Ching. In general I Ching propounds the fact that everything changes and the transformation from one stage to another is cyclic, transitional and on-going (Chen, 2009). In regards to the life cycle of building, there exist certain truth or rationality. For instance, the legal ownership within a building has to be aligned with the physical walls. The inconsistency that occurs will create encroachment, which will result in certain legal disputes.

3.0 BUILDING INFORMATION MANAGEMENT IN RELATION TO *IMAGE, NUMBER* AND *RATIONALITY*

3.1 Image

In the life cycle of building, building data are produced from the design model of a building before the building is constructed. After the building is constructed, through mapping technique such as laser scanning or photogrammetry, 3D building models can also be created. To demarcate the property boundaries within the building, strata ownership has sometimes been produced as well depending if the strata subdivision is needed. The physical construct of the building, the building design model, the 3D building model and the legal strata ownership of the building are the *image*s (see Figure 3). These images can evolve over times, such as the demolition of the building or the addition of new features to the building. With these changes it requires the maintenance of the building data.

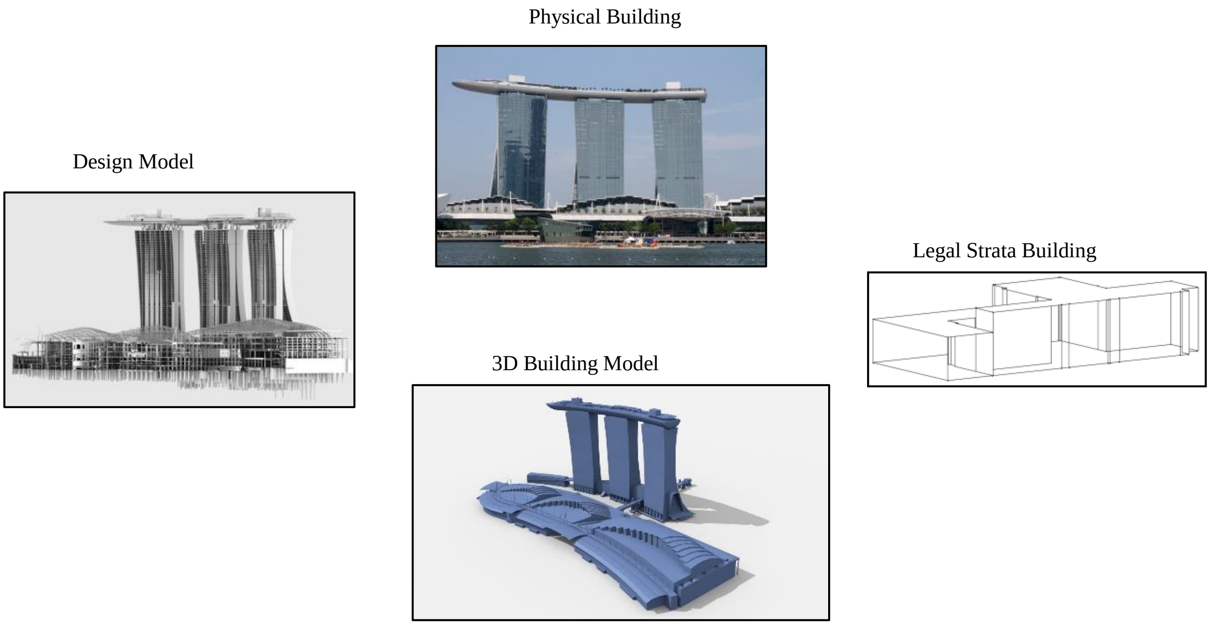


Figure 3. Images of a building

3.2 Number

The *images* can be represented as digital computational models in formats such as CityGML and LandXML.

CityGML

CityGML allows computer systems to process and analyse building information such as class, function, roofType and measuredHeight as depicted in Figure 4. In addition to the attribute information, the geometrical information from CityGML also enables Geographical Information System (GIS) to perform spatial analysis and understand the building's whereabouts. Commonly CityGML is used to represent 3D city models, which are collected and modeled through mapping techniques (Soon and Khoo, 2017; van den Brink *et. al.*, 2013).

```xml
▼<cityObjectMember>
 ▼<bldg:Building gml:id="GML_7b1a5a6f-ddad-4c3d-a507-3eb9ee0a8e68">
  ▼<externalReference>
   ▼<externalObject>
    ▼<uri>
      http://wiki.tudelft.nl/pub/Research/ISO19152/ImplementationMaterial/LADMOntology.owl#PhysicalSpaceBuildingUnit
     </uri>
    </externalObject>
   </externalReference>
   <gml:name>HDB</gml:name>
   <bldg:class codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_class.xml">1000</bldg:class>
   <bldg:function codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_function.xml">1000</bldg:function>
   <bldg:roofType codeSpace="http://www.sig3d.org/codelists/standard/building/2.0/_AbstractBuilding_roofType.xml">1000</bldg:roofType>
   <bldg:measuredHeight uom="#m">26.687</bldg:measuredHeight>
  ▶<bldg:lod1Solid>...</bldg:lod1Solid>
  ▶<bldg:address>...</bldg:address>
  </bldg:Building>
</cityObjectMember>
```


Figure 4. A snapshot of CityGML Building LOD 1 (Soon and Khoo, 2017)

LandXML

Legal land and strata boundaries can be represented in the format of LandXML (http://www.landxml.org). LandXML has been adopted for automation in cadastral processing and approval in Australia (Shojaei *et. al.*, 2012), New Zealand (Gulliver *et. al.*, 2016) and Singapore (Soon *et. al.*, 2016) under the Intergovernmental Committee on Surveying and Mapping (ICSM, http://www.icsm.gov.au) ePlan Working Group (Cumerford, 2010). The submissions in LandXML from the registered land surveyors to the approving authorities allow for computer systems to process and ensure the submissions are in compliance with the respective jurisdictions' cadastral survey regulations.

3.3 Rationality in Integrating Legal Space and Physical Space

Soon *et. al.* (2014) demonstrated the integration between the legal space represented in LandXML and physical space from CityGML using the LADM OWL Ontology (Soon, 2013) (see Figure 5). The *hasLegalSpace* relation had been created to integrate the two spaces. The mappings between ePlan model, LADM OWL and CityGML schema however were made at the schema level or in the *Number* perspective. The integration was not considered from the *Image* and *Rationality* perspectives. Even the two spaces can be integrated at the schema level, the physical construct of the building can be altered but the strata boundaries are still residing within the original physical walls. This will create inconsistency in the *Rationality* perspective.

In Singapore, strata boundaries should be in the middle of the physical walls of a building. This logics or truth may be different in other countries such as Australia, which may consider the physical walls as the strata boundaries. One can consider *Rationality* as cadastral survey rules and regulations that depend upon individual jurisdictions' practices. One can also include other rules and regulations by local authorities for the approval of design models before a construction takes place. *Rationality* can be implemented as Description Logics to support reasoning.

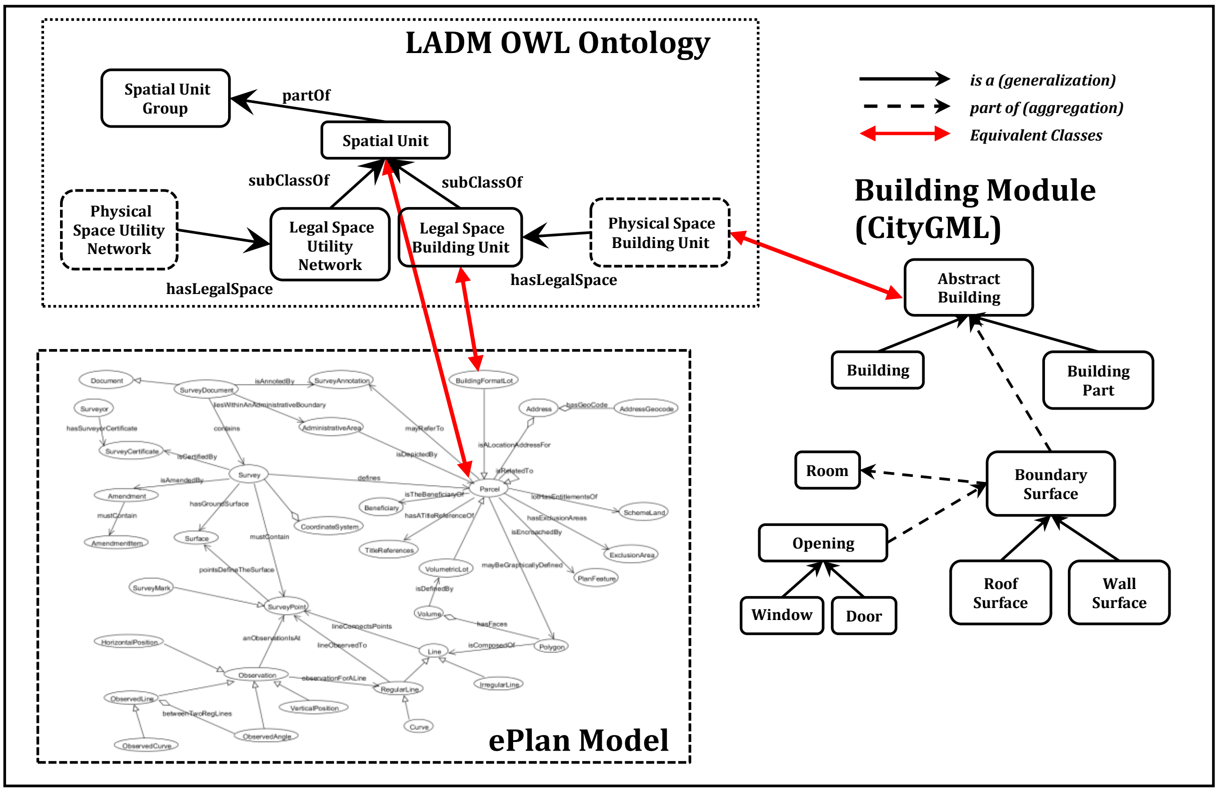


Figure 5. The *hasLegalSpace* relation has created to integrate legal space and physical space (source: Soon *et al.*, 2014)

3.4 Changes in Image, Number and Rationality

Changes can happen in *Image*, *Number* and *Rationality*. For example, in respect to Image, strata lots of a building can be amalgamated thus the whole strata ownership boundaries are changed. A physical building can be extended with new building parts such as balcony and garage. The 3D building model as a result will also be updated with the new structure.

In regards to *Number*, one digital model can be changed into a different format for example through data conversion. The source model and target model can be different syntactically and semantically, e.g. between CityGML and LandXML, or between vector and raster.

Rules and regulations can be changed as well to meet the needs of the citizens and to improve the existing processes, for example the change of Level of Detail (LoD) notion from CityGML 2.0 to 3.0. In addition, to better manage the underground development in Singapore, the limited depth of 30 meter has been introduced where the land beyond 30 m depth belongs to the government.

4 CASE STUDY: CONTEXTUALISING LADM OWL ONTOLOGY TO INTEGRATE LEGAL SPACE BUILDING UNIT AND PHYSICAL SPACE BUILDING UNIT

Ontology can be contextualised based on the three fundamental perspectives *Image*, *Number* and *Rationality*. Let us focus on the three concepts from the LADM OWL ontology that were used to integrate ePlan model and CityGML schema previously discussed in Soon *et. al.* (2014).

As illustrated in Figure 6, all three concepts are bound to perspectives: Image, Number and Rationality. The following framework is assumed implemented in a system where the concepts from the LADM OWL ontology are treated as a concept map on which one can click the concepts interactively. For example, when one clicks on a concept from the concept map, the system will respond with certain interactions such as navigating to a different perspective.

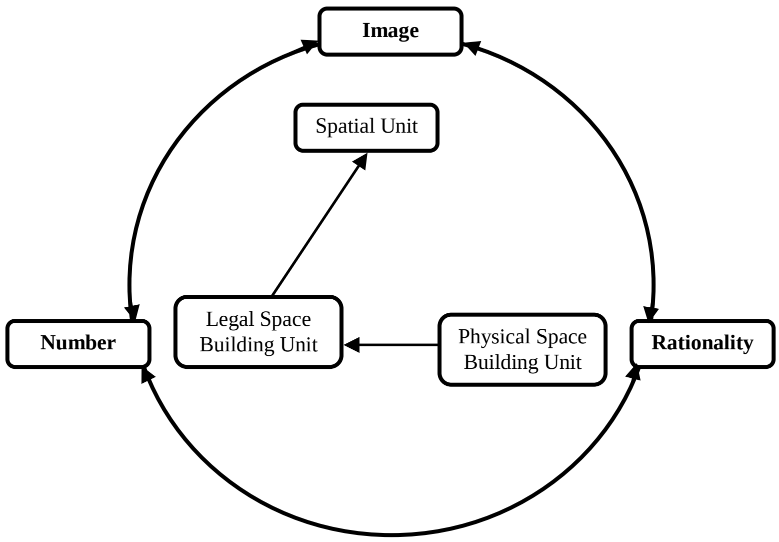


Figure 6. The three concepts as they are bound to perspectives: Image, Number and Rationality

The concepts can be viewed from one perspective to another. For example, when the concept Legal Space Building Unit is clicked and is viewed from the *Image* perspective, the strata boundaries that are linked to the concept will be shown. If the concept is viewed from the *Number* perspective, the respective LandXML files storing the strata information will be displayed, and if it is in the *Rationality* perspective, the strata rules and regulations will be described. In the same vein, when clicks on the Physical Space Building Unit concept, one will be able to see the 3D building models from the *Image* perspective, the respective CityGML files from the *Number* perspective and the topological rules from the *Rationality* perspective. The system enables to contextualise the LADM OWL ontology in different perspectives while allowing data integration from legal space and physical space in different formats.

The *Rationality* perspective can also be used as integrity checks. For instance, one may convert a BIM design model into a CityGML model and considers the converted CityGML model as representing the physical space of a building and integrates it with the legal space of the building in the system. Inconsistencies will occur when the *Rationality* perspective reasons that the legal boundaries of the building do not reside within the physical walls from the converted CityGML model.

The three perspectives should always be synchronised and harmony with one another. When inconsistencies occur in one of the three perspectives, error messages will be prompted to inform the users about the inconsistencies. This is to prevent information loss when integrating data using ontology.

5 CONCLUSIONS

The paper demonstrated a framework to contextualise ontologies in order to reduce information loss when ontologies are used. Ontologies should not be used merely based on what the ontologies describe, one should also consider the different perspectives the concepts in the ontologies represent.

The framework presented in the paper is still conceptual and at its early stage. The framework requires an implementation. The next step is to formalise the ontologies to include the perspectives with a formal language like OWL. Not only the ontologies should be contextualised in different perspectives, but also to be able to link with data which can be stored in different formats such as CityGML and LandXML.

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BIOGRAPHICAL NOTES

Kean Huat Soon is a Principal Surveyor at the Land Survey Division of Singapore Land Authority. He is involved in the development of the new cadastral system in the Division to support automated cadastral processing using SG LandXML. He also takes part in the 3D National Mapping project, which is primarily based on CityGML schema. He earned a Msc in Geography from the Pennsylvania State University, a Msc in Geoinformatics and Bachelor of Surveying (Land) from University of Technology Malaysia. His research interests include semantic interoperability, data modeling, cadastral information system and ontology.

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